

# **RFCA Stakeholder Focus Group Meeting Agenda**

**When: January 17, 2001 3:30 - 6:30 p.m.**

**Where: Anne Campbell Room, Arvada City Hall  
8101 Ralston Road**

- 3:30-3:40 Introductions, Agenda Review, 1/3/01 Meeting Minutes Review
- 3:40-3:55 Progress Report on Agency Use of Focus Group Input
- 3:55-4:35 New Science Outline and Wind Tunnel Detail Presentation/  
Discussion
- 4:35-5:05 RSAL Workshop Topics and Formats
- 5:05-5:20 Break
- 5:20-5:50 RESRAD Model Workshop – Objectives and Topics
- 5:50-6:15 Land Use Scenarios Presentation and Frame Discussion
- 6:15-6:30 Set Future Agendas and Review Meeting
- 6:30 Adjourn

## RFCA Stakeholder Focus Group Attachment A

Title: Agenda for January 17, 2001 Focus Group Meeting

Date: January 11, 2001

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# RFCA Stakeholder Focus Group

## 1/17/01 Meeting Participant's List

NAME		ORGANIZATION / COMPANY
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Christine	Bennett	AlphaTRAC, Inc.
Ray	Betts	
Ken	Brakken	DOE, RFFO
Laura	Brooks	Kaiser-Hill Company, LLC
John	Corsi	Kaiser-Hill Company, LLC
Gerald	DePoorter	RFCAB
Rick	DiSalvo	US DOE - RFFO
Sam	Dixon	City of Westminster
Steve	Gunderson	CDPHE
Mary	Harlow	City of Westminster
Jerry	Henderson	RFCAB
Reed	Hodgin	AlphaTRAC, Inc.
Victor	Holm	RFCAB
Jeremy	Karpatkin	US DOE - RFFO
Paul	Kilburn	JCNA
Denise	Klimas	U.S. Fish & Wildlife Service
Ken	Korkia	RFCAB
Joe	Legare	DOE
Ann	Lockhart	CDPHE
Carol	Lyons	City of Arvada
Sandi	MacLeod	DOE
John	Marler	RFCLOG
Tom	Marshall	Rocky Mountain Peace and Justice Center
Dan	Miller	Natural Resources and Environment Section
		Colorado Department of Law
LeRoy	Moore	RMPJC
Diane	Niedzwiecki	CDPHE
Bob	Nininger	Kaiser-Hill Company, LLC
Sheila	Plunkett	Rocky Mountain Peace and Justice Center
Karen	Reed	EPA
Tim	Rehder	US EPA
Dave	Shelton	Kaiser-Hill Company, LLC
Carl	Spreng	CDPHE
Noelle	Stenger	RFCAB

ADMIN RECORD

## **New Scientific Information Report Outline**

- I. Introduction
  - A. Background
  - B. Purpose
- II. Fires
  - A. Front Range Fires
    - 1. Available Data
    - 2. Likelihood of Fires
    - 3. Impact of Fires
  - B. Los Alamos, Hanford and Idaho Fires
    - 1. Available Data
    - 2. Impact of Fires
- III. Air Resuspension Model
  - A. Evaluate within Selected Model (Task 2)
- IV. Wind Tunnel Studies
  - A. Controlled Burn and Lightning Fire
  - B. Impacts During Fires
  - C. Impacts After Fires
- V. Actinide Migration Evaluation Studies
  - A. Particulate Transport and Solubility
  - B. Soil Erosion and Surface Water Sediment Transport
  - C. Air Transport and Deposition
  - D. Uranium in Groundwater
  - E. Actinide Contaminated Concrete
  - F. Actinide Pathway Report
- VI. Status of Other Topics
  - A. Dose Conversion Factor
  - B. BEIR Studies
  - C. Solubility of Plutonium Oxide
- VII. Conclusions
  - A. Summary of Impacts on RSALs
  - B. Recommendations for Incorporation into RSALs

# WORKSHOP 1.

## THE CODE AND ITS USE

- Workshop Purpose
- Workshop Logistics
- Workshop Schedule

# WORKSHOP 1 PURPOSE

The purpose of Workshop 1 is to:

- Give an overview of what RESRAD 6.0 calculates.
- Describe in general terms how the calculations are performed.
- Describe what is required to be able to run the code.

# WORKSHOP 1 PURPOSE

- Walk through a sample problem step-by-step.

This would include:

Going through the input step-by-step.

Running the Code.

Examining the output files and graphics,  
working through them one-by-one and  
explaining how to interpret them.

# WORKSHOP 1 LOGISTICS

- Every participant should have a computer or at least share with only one other person a computer that has RESRAD 6.0 loaded and running. Several participants may have their own laptop computers with RESRAD 6.0 already loaded and it is assumed that they will bring them.

# RESRAD 6.0 WORKSHOPS

A Proposal by:

Gerald L. DePoorter, Ph.D.

Emeritus Professor of Metallurgical  
and Materials Engineering

Colorado School of Mines

# RESRAD 6.0 WORKSHOPS

Two Workshops are Suggested:

- RESRAD 6.0 The Code and Its Use
- Parameter Selection for RSALs at the RFETS

# WORKSHOP 1 LOGISTICS

- The workshop presenter must have a computer linked to a projector so that his or her process can be followed by all the workshop participants on a large screen at the front of the room.
- The sample problem must be gone through slowly and carefully enough so that no participants get lost.

# WORKSHOP 1 LOGISTICS

- The D.O.E. should determine the computer requirements of the group of participants before the workshop in order that enough computers are available.
- The room for the workshop should be adequate to meet the working needs of the anticipated number of participants.

# WORKSHOP 1 SCHEDULE

- The workshop should be scheduled for a full day - 8AM to 5PM. In addition to a lunch break, there needs to be a morning and afternoon break.
- An evening session should be provided for those less technically inclined or unable to attend for the full day.

# WORKSHOP 1 SCHEDULE

- The first workshop should be held as soon as is practical.
- Potential participants should be surveyed early enough on to determine computer and room size needs.

# WORKSHOP 2

## Parameter Selection for RSALs at the RFETS

- Workshop Purpose
- Workshop Logistics
- Workshop Schedule

# WORKSHOP 2 PURPOSE

The purpose of Workshop 2 - Parameter Selection for RSALs at the RFETS - is to assemble together technical experts in a panel format to discuss, debate, and answer questions on the selection of the parameters to be used in the RESRAD 6.0 calculations for the RFETS RSALs.

# WORKSHOP 2 LOGISTICS

- D.O.E should consult with the RFCA focus group, the RFCLOG, and the RFCAB on the make up of the panel of experts.
- The panel members should be given sufficient lead time to adequately prepare for the panel discussion.

# WORKSHOP 2 LOGISTICS

- Again, a room large enough should be provided for the workshop.
- Appropriate audio-visual aids should be available to the panel.
- The panel discussion should be facilitated.

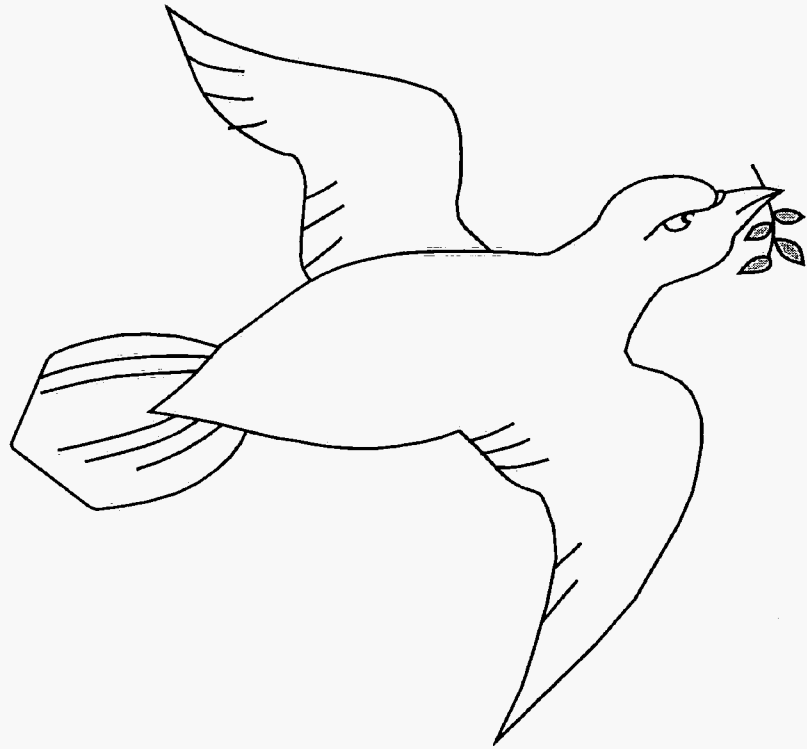
# WORKSHOP 2 SCHEDULE

- The workshop should be scheduled for a full day - 8AM to 5PM. In addition to a lunch break, there needs to be a morning and afternoon break.
- An evening session should be provided for those less technically inclined or unable to attend for the full day.

# WORKSHOP 2 SCHEDULE

- Workshop 2 should be held as soon as is practical after Workshop 1.

# QUESTIONS?



# SUMMARY OF LAND USE AND EXPOSURE SCENARIOS TO BE USED IN CALCULATING THE RSAL FOR ROCKY FLATS CLEANUP

## LAND USE SCENARIOS

**Open Space (Buffer Zone Only - RFCA Scenario)** - The Open Space Scenario anticipates access by the public to large portions of the Site in a manner similar to how open space areas similar to RFETS are used in Jefferson or Boulder county. Stay times and open space useability would be based upon the most recent survey data from Jefferson County.

**Office Worker (Industrial area only - RFCA Scenario)** - The Office Worker Scenario is described by RFCA and is oriented toward the potential for the industrial area to be the site of commercial activity post interim site condition. There are currently no plans for such use.

**Refuge Worker (considered most likely future land user for bufferzone)** - If the proposed legislation for designation of Rocky Flats as a wild life refuge is adopted, the most likely future user will be the Wildlife Refuge worker (WRW). Significant survey data from California and Colorado has been collected regarding the activities associated with the WRW, and will be used to help define the RF WRW activities and potential for exposure.

**Suburban Resident (failure of institutional controls)** - Some institutional controls are anticipated as part of the final site remedy. If ICs fail, the default land-use scenario will be a future suburban resident. This is based in large measure on the development patterns being witnessed today in Northeast Denver.

**Resident Rancher** - The Resident Rancher is not considered realistic, either for the future land user, or for institutional controls failure, but RSALs protective of the resident rancher will be calculated.

## EXPOSURE SCENARIOS

**25 mrem/yr** - 25mrem/yr comes from the NRC decommissioning rule which has been determined by EPA and CDPHE to be an ARAR for the Rocky Flats cleanup. If 25 mrem/yr is used, but it is outside the CERCLA risk range, then additional cleanup beyond the action level would be required to ensure final cleanup falls within the CERCLA risk range.

**Risk =  $10^{-4}$  -  $10^{-6}$**  - CERCLA requires the final cleanup to be within the CERCLA risk range of  $10^{-4}$  -  $10^{-6}$ . This represents a range of two orders of magnitude or a factor of 100. The RSAL will be calculated for each order of magnitude as a basis for comparison of risk, and for comparison to the dose-based approach.

Land Use Scenarios	RSAL TABLE FOR SELECTED SCENARIOS, DOSE AND RISK			
	25 mrem/yr	Lifetime Risk = $10^{-4}$	Lifetime Risk = $10^{-5}$	Lifetime Risk = $10^{-6}$
Open Space User - Adult				
Open Space User - Child		[no risk calc]	[no risk calc]	[no risk calc]
Office Worker				
Wildlife Refuge Worker (most likely future land use)				
Suburban Resident - Adult				
Suburban Resident - Child		[no risk calc]	[no risk calc]	[no risk calc]
Resident Rancher - Adult				
Resident Rancher - Child		[no risk calc]	[no risk calc]	[no risk calc]

Once the model has been selected (anticipated to be RESRAD 6.0), distributions have been established for sensitive parameters, and deterministic values have been set for non-sensitive parameters (or sensitive parameters for which a distribution is not appropriate) then computer runs will be completed for each scenario and for each dose or risk value. The results will be summarized in the table above.

# **RFCA Stakeholder Focus Group**

## **January 17, 2001**

### **Meeting Minutes**

#### **INTRODUCTION AND ADMINISTRATIVE**

A participants list for the January 17, 2001 Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group meeting is included in this report as Appendix A.

Reed Hodgins of AlphaTRAC, Inc., meeting facilitator, reviewed the purpose of the RFCA Stakeholder Focus Group and the meeting rules for this group. Introductions were made.

Reed reviewed the meeting agenda, which included:

- Progress Report on Agency Use of Focus Group Input
- New Science Outline and Wind Tunnel Detail Presentation/ Discussion
- Radioactive Soil Action Level (RSAL) Workshop Topics and Formats
- RESRAD Model Workshop – Objectives and Topics
- Land Use Scenarios Presentation and Frame Discussion

Reed asked the Focus Group if there were any changes or additions / corrections to the January 3, 2001 meeting minutes.

A member of the Focus Group asked why questions, answers, and comments in the meeting minutes were not attributed. Reed responded that this was done so that discussions would be associated with the focus group as a whole, rather than as conversations among individuals.

Reed indicated that a large effort was involved in producing meeting minutes at the current level of detail. He asked if this amount of detail was useful to the group. Although one member asked for briefer minutes, a number of Focus Group members indicated that the existing level of detail was useful and that the minutes were used for reviews and briefings. Reed agreed to continue producing meeting minutes at the current level and invited members to contact him with further suggestions.

#### **RSAL REVIEW CONFERENCE CALLS**

**ADMIN RECORD**



Reed introduced Jerry Henderson of the Rocky Flats Citizens Advisory Board (RFCAB) with a concern about the RSAL conference calls. Jerry noted that the RSAL conference calls had been discontinued and asked the group if there was a need for these calls. A group discussion followed.

The U.S. Department of Energy (DOE) noted that the conference calls (which were expensive and effort intensive) had been discontinued because low participation by the community (one or two participants per call) indicated that there was no real need for the calls. A member of the Focus Group noted that the calls had not been well advertised, and that may have contributed to the lack of participation.

The discussion led toward a belief that the summary information presented in the conference calls would be useful for members of the community who could not attend the RSAL Working Group meetings.

It was noted that a summary of decisions and action items is created at each RSAL Working Group meeting. It was agreed that this summary would be submitted to AlphaTRAC, Inc., which would distribute it by email to Focus Group members.

It was also noted that John Marler develops summaries of the RSAL Working Group meetings for the Rocky Flats Council of Local Governments (RFCLOG). He agreed to check with the RFCLOG to determine if the summaries can be more widely distributed. If the RFCLOG agrees, AlphaTRAC, Inc. will distribute these summaries to Focus Group members by email.

## **PROGRESS REPORT ON AGENCY USE OF THE FOCUS GROUP INPUT**

One of the primary goals of the RFCA Stakeholders Focus Group is to provide input to the RFCA Agencies regarding decisions about cleanup at Rocky Flats. The RFCA Agencies have agreed to periodically provide feedback to the Focus Group on how the group's input is being used.

Tim Rehder of the U. S. Environmental Protection Agency (EPA) stated that Focus Group input was currently being used to create a revision of the Regulatory Analysis (Task 1) report on the RSAL Review.

He indicated that one key input was the need to address a preference in the Nuclear Regulatory Commission (NRC) regulation for cleanup to unrestricted release. He stated that the revised regulatory analysis approach calls for development of an RSAL for anticipated use and an RSAL number for unrestricted use. Then the DOE would have to demonstrate why they can not achieve the RSAL for unrestricted use in each individual cleanup using the As Low As Reasonably Achievable (ALARA) approach.

Joe Legare of DOE responded, stating that some of the language was still being negotiated among the RFCA Agencies. He indicated that DOE's perspective was to use ALARA to prove that cleanup at a specific site would result in doses or risk that were "as low as reasonably achievable" and that the unrestricted use RSAL value would be a target. He indicated that there was no burden of proof for why the unrestricted value could not be reached, but rather a burden of proof for why the cleanup level achieved was "as low as reasonably achievable." DOE and EPA agreed that they were in agreement and that the language would be worked out.

Tim stated that another influence from the Focus Group was on the choice of risk level within the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) risk range. Based on Focus Group input, the full CERCLA range will be examined, not just  $10^{-4}$ . This will be accomplished by calculating RSAL values for  $10^{-4}$ ,  $10^{-5}$ , and  $10^{-6}$ .

Tim also noted that the Focus Group had asked for an independent peer review of the RSAL Review process, and that the agencies had agreed and DOE was funding the activity.

Tim stated that the Focus Group had asked for Workshops concerning the RSAL review and that DOE had agreed to fund the workshops.

Steve Gunderson of the Colorado Department of Public Health and Environment (CDPHE) added that the RFCA Agencies were putting a great deal of effort into involving the community through the Focus Group and other means. He stated that the

effort was much greater than originally anticipated. Most of this effort was going to informing the community about the cleanup process and responding to community requests for analysis and information.

Joe Legare of DOE said that the agencies were working very hard to meet their commitment of "no surprises." He reminded the members of the Focus Group that this was a two-way street.

Reed closed the conversation by noting that the RFCA Focus Group is a unique attempt on the part of the agencies and the community to work collaboratively throughout the cleanup process.

## **NEW SCIENCE OUTLINE AND WIND TUNNEL DETAIL PRESENTATION / DISCUSSION**

### **New Science Outline**

Joe Legare of DOE briefed the Focus Group on the current outline for the New Science Report for the RSAL Review (see Appendix B for the outline). Joe introduced Sandi MacLeod of DOE and indicated that Sandi would be authoring the report. He asked that the Focus Group review the outline and the information provided in the briefing and submit comments and suggestions (especially for additional topics) back to Sandi. He then briefly summarized progress in the main areas of new science.

### **Fires**

Information and knowledge gained from the wildfires of 2000 at DOE sites will be collected and reported.

A member of the Focus Group asked that the findings from the Secretary of Energy's national review panel on wildfires be incorporated. DOE agreed.

### **Air Resuspension Model**

Radian Corporation has been contracted to review and report on the differences in the air resuspension approaches in the three versions of the RESRAD model – Version 5.8, the Risk Assessment Corporation (RAC) version and Version 6.0.

### **Wind Tunnel Studies**

The results and implications from the recent wind tunnel studies of resuspension following fires at Rocky Flats (prescribed burn and wildfire) will be analyzed and reported.

### **Actinide Migration Evaluations**

DOE and Kaiser-Hill have been investigating particulate transport and solubility for some time. The report will summarize these new findings about the behavior of plutonium in the environment.

### **Status of Other Topics**

#### **Biological Effects of Ionizing Radiation (BEIR) Studies**

The New Science Report will summarize the latest findings from the BEIR studies.

Joe indicated that the schedule for the New Science report would be updated in a meeting on January 18, 2001. He asked for comments.

A member of the Focus Group indicated that the new findings on cancer risk slope factors and dose conversion factors should be included in the New Science Report. Joe agreed.

## **Wind Tunnel Detail Presentation**

Bob Nininger of Kaiser-Hill gave a summary briefing on the Wind Tunnel study.

Bob stated that the wind tunnel studies had been conducted to gather site-specific information on the resuspension of soil by wind at Rocky Flats. It was felt that the generic data found in the literature may not be sufficiently representative for this important exposure pathway.

Bob presented a briefing that summarized three topics:

- The wind tunnel and its operation,
- The wind tunnel tests at Rocky Flats, and
- Initial results from the wind tunnel tests.

The briefing slides are unavailable. They will be sent as soon as received.

A discussion followed the presentation.

A member of the Focus Group noted that the reduction in resuspension over time since the prescribed burn (as shown in wind tunnel test results) could be due to factors other than vegetation recovery after the burn. For instance, soil blown away by the wind while the surface was bare would not be available for later resuspension.

It was noted that the wind tunnel is not an exact replication of the winds at Rocky Flats, because the gustiness of the winds could not be fully reproduced in the wind tunnel.

A member of the Focus Group asked how long after a wind event would particulates be available for resuspension again. Bob answered that cracking of the soil, freeze/thaw cycles, etc. would probably make material available again in 1 – 2 weeks.

A member of the Focus Group noted that a probabilistic distribution of mass loading for resuspension would be the hardest input to develop for the RESRAD model. Bob responded that the episodic nature of wind resuspension would make it difficult to come up with the representative annual values that RESRAD would need, but that the meteorological data needed to do the analysis was available.

A comment was made that a peer review of the original wind tunnel study questioned the placement of the wind tunnel with respect to the wind. Bob responded that the wind tunnel investigated the microphysics of resuspension and that it generated its own wind.

A Focus Group member noted that a peer reviewer had commented that the directional alignment of the wind tunnel might be important because winds from different directions might resuspend material differently. Bob responded that the wind tunnel was set down on several undisturbed patches within an overall study area. There was no attempt to align it in specific directions because it wasn't felt that there was a directional preference for resuspension.

## **RSAL WORKSHOPS TOPICS AND FORMATS**

Reed introduced the topic, saying that the objective for the discussion was to decide on the topics and formats for the upcoming RSAL workshops. He told the group that he had asked Gerald DePoorter to develop and present a strawman to initiate the discussion, in part because Gerald understood the background for a similar request made by the RFCAB.

Gerald began his presentation by emphasizing that he was not representing the RFCAB, but was rather presenting his ideas as an individual member of the Focus Group (see Appendix C for Gerald's slide presentation). He summarized a two workshop series:

Workshop 1: RESRAD 6.0 and Its Use, and  
Workshop 2: Parameter Selection for RSALs at the RFETS.

He indicated that the purposes for the RESRAD workshop would be:

- Overview of what RESRAD 6.0 calculates,
- Describe in general terms how the calculations are performed,
- Describe what is required to be able to run the code, and
- Walk through a sample problem step-by-step.

Hands-on computer operation (model runs) by the participants would be a distinguishing feature of this workshop.

The purpose for the Parameter Selection workshop would be:

- Assemble together technical experts in a panel format to discuss, debate, and answer questions on the selection of the parameters to be used in the RESRAD 6.0 calculations for the RFETS RSALs.

A group discussion followed Gerald's presentation.

The group was divided on whether hands-on training for operating RESRAD 6.0 was an important workshop activity.

The idea of holding training as a separate meeting or a separate session during the workshop was raised.

The possibility of using local resources to conduct initial RESRAD training was brought up, to be followed by an "advanced" session with experts on the code from Argonne National Laboratory.

It was noted that it would be essential that experts from Argonne National Laboratory and from the RAC (John Till) participate in person.

Ways to minimize the number of separate trips and maximize the usefulness of the out-of-town experts were presented and discussed.

The need to address dose conversion factors and risk slope factors was raised.

The possibility of having a separate workshop on the regulatory basis for RSALs was raised. This workshop might include representatives from EPA, DOE, and NRC.

At the end of the discussion the following meetings were outlined:

1. RESRAD Training Class

- Occurs before the main workshops
- Taught by local resources

**2. A two-day Workshop**

**Day 1: RESRAD**

Early morning: "Advanced Seminar on Operating RESRAD"

Taught by: Argonne National Laboratory and RAC

Late Morning and Afternoon: "The RESRAD Model and its Application to RSALs at Rocky Flats"

**Topics:**

- Basis for RESRAD
- Application of RESRAD in RAC study
- Changes to RESRAD and effects
- Risk / probability in RESRAD 6.0
- Parameters chosen for RESRAD
- Applicability to RFETS
- Ground and surface water in RESRAD
- RAC views on RESRAD implementation
- Questions regarding RAC study
- Questions regarding 6.0 source code

**Day 2: Parameters for RSAL Development at Rocky Flats**

Topics to be determined, but will include Dose Conversion Factors and Risk Slope Factors

Taught by: Argonne National Laboratory and RAC

A suggestion was made that a committee be formed to develop a detailed workshop design for submittal to the Focus Group at the January 31, 2001 meeting. The following Focus Group members volunteered to develop the design:

- Victor Holm,
- Gerald DePoorter,
- Kent Brakken,
- John Marler.

## LAND USE SCENARIOS PRESENTATION AND FRAME DISCUSSION

Steve Gunderson of CDPHE briefed the Focus Group on the land use scenarios selected for the RSAL Review. A summary of the land use and exposure scenarios is provided in Appendix D.

Steve indicated that five land use scenarios would be analyzed in the RSAL Review:

**Open Space (Buffer Zone Only - RFCA Scenario)** - The Open Space Scenario anticipates access by the public to large portions of the Site in a manner similar to in a manner similar to how open space areas similar to RFETS are used in Jefferson or Boulder county. Stay times and open space usability would be based upon the most recent survey data from Jefferson County.

**Office Worker (Industrial area only - RFCA Scenario)** - The Office Worker Scenario is described by RFCA and is oriented toward the potential for the industrial area to be the site of commercial activity post interim site condition. There are currently no plans for such use.

**Refuge Worker (considered most likely future land user for bufferzone)** - If the proposed legislation for designation of Rocky Flats as a wild life refuge is adopted, the most likely future user will be the Wildlife Refuge worker (WRW). Significant survey data from California and Colorado has been collected regarding the activities associated with the WRW, and will be used to help define the RF WRW activities and potential for exposure.

**Suburban Resident (failure of institutional controls)** - Some institutional controls are anticipated as part of the final site remedy. If ICs fail, the default land-use scenario will

be a future suburban resident. This is based in large measure on the development patterns being witnessed today in Northeast Denver.

**Resident Rancher** - The Resident Rancher is not considered realistic, either for the future land user, or for institutional control failure, but RSALs protective of the resident rancher will be calculated.

Steve indicated that RSALs would be calculated for both adult and child user for the open space user, the suburban resident, and the resident rancher. Four different adult exposure scenarios would be applied for all land use scenarios:

- 25 mrem dose,
- $10^{-4}$  risk,
- $10^{-5}$  risk, and
- $10^{-6}$  risk.

The 25 mrem dose exposure scenario would be calculated for child users.

A brief discussion followed the presentation.

A member of the Focus Group asked about the scientific basis for choosing the scenarios. The agencies responded that the basis for the scenarios selected would be discussed in the Task 1 report, while the details of the scenarios would be presented in the Task 3 report.

A member of the Focus Group asked if it would be possible to assume a longer residency time than the 30 years recommended in CERCLA. The agencies responded that RESRAD could run a longer residency time, that the choice of 30 years is a parameter issue rather than a modeling issue. The 30 year exposure duration is used because it is the 90<sup>th</sup> percentile residency period for the United States. There is some guidance from EPA Region VI that 40 years may be more appropriate for a rancher.

A member of the focus group commented on the CERCLA term "reasonably maximally exposed individual." "Does that mean the period that the wildlife refuge might exist? Or does that mean for the period that the plutonium might remain dangerous? Let's be real and think about that question and not simply assume that a bill passed in Congress

next year or the year after is going to define conditions at Rocky Flats forever. We all know that isn't the case."

CDPHE commented that the RAC study had shown that the period immediately after cleanup was responsible for most of the dose from the residual contamination and that contributions from later years drop off rapidly due to weathering and other physical forces.

Steve Gunderson of CDPHE closed the discussion by pointing out that residual contamination would remain after cleanup at Rocky Flats. Crafting the agreement for long term stewardship – institutional controls, surface water protection, etc. will be a critical step in the overall cleanup process and will be an essential dialog among the agencies and the community.

## **Agenda Items**

The focus group agreed on the following topics for the next two meetings:

January 31, 2001

- RSAL workshop design team report back and discussion
- Regulatory Analysis questions for peer reviewers
- Land use scenarios – continued discussion

February 14, 2001

- Revision 2 of the Regulatory Analysis report - discussion
- RSAL Working Group progress report
- Review of RESRAD 6.0 approach to air pathway

## **ADJOURNMENT**

The RFCA Stakeholder Focus Group meeting was adjourned at 6:30 p.m.

## **Summary of Actions and Commitments**

- Provide summaries of RSAL Working Group meetings (action items and decisions) to AlphaTRAC, Inc. for distribution (Agencies).
- Distribute summaries from RSAL Working Group meetings to Focus Group members via email (AlphaTRAC, Inc.).
- Check with the RFCLOG to see if the interested members of the community can be copied on the RSAL Review Working Group Meeting Summaries developed for RFCLOG members (John Marler).
- Distribute RFCLOG summaries from RSAL Working Group meetings to Focus Group members via email if RFCLOG agrees (AlphaTRAC, Inc.).
- Incorporate findings from DOE national wildfire review panel in New Science Report (DOE).
- Incorporate new findings on cancer risk slope factors and dose conversion factors should in the New Science Report (DOE).
- Develop a proposed design for two RSAL Workshops and present the design to the Focus Group at the January 31, 2001 RFCA Focus Group meeting (Workshop Design Committee).
- Identify guidance used in selecting land use scenarios for RSAL development and provide to the Focus Group at the January 31, 2001 Focus Group meeting (DOE).

**Appendix A  
1/17/01 Participants List**

**Appendix B**  
**Joe Legare: New Scientific Information Report Outline**

**Appendix C  
Gerald DePoorter: RESRAD 6.0 Workshops**

**Appendix D**  
**Steve Gunderson: Summary of Land Use and Exposure**  
**Scenarios to be used in Calculating the RSAL for Rocky Flats**  
**Cleanup**

## RFCA Stakeholder Focus Group Attachment B

Title: Meeting Minutes for January 17, 2001 Focus  
Group Meeting

Date: January 25, 2001

Author: C. Reed Hodgins  
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ADMIN RECORD

~~SECRET~~

**RADIONUCLIDE SOIL ACTION LEVEL**  
**REGULATORY ANALYSIS**

**PURPOSE**

The Department of Energy (DOE), the Environmental Protection Agency (EPA) and the Colorado Department of Public Health and the Environment (CDPHE) are currently reevaluating the Radionuclide Soil Action levels (RSALs) that will govern much of the cleanup at Rocky Flats. Among the reasons for the reevaluation are that the draft EPA Radiation Sites Cleanup Rule that was used as a basis for the current RSALs is defunct and DOE, EPA and CDPHE are also considering the recommendations of the Radionuclide Soil Action Level Oversight Panel regarding its review of the RSALs.

This paper discusses relevant regulatory and guidance developments and makes a proposal as to what should form the basis of a new RSAL. This analysis is specific to the Rocky Flats Environmental Technology Site and The Rocky Flats Cleanup Agreement (RFCA), signed by DOE, CDPHE and EPA in 1996, and is not intended to represent any agency's positions with respect to other sites or other cleanup agreements.

In many instances this paper summarizes or paraphrases specific RFCA or regulatory language, to (hopefully) improve readability. The interested reader should refer to the cited authority for the specific text.

**BACKGROUND**

In October of 1996 DOE, EPA and CDPHE established an action level for radionuclide contamination in soils at Rocky Flats<sup>b</sup>. In short, An action level is a numeric level that, when exceeded, triggers an evaluation, remedial action, and/or management action. The radionuclide soil action level (RSAL) is expressed in terms of the amount of radioactivity per unit mass of soil; specifically picocuries/gram (pCi/g). Having an RSAL that is protective of human health is a key element in planning and executing the overall cleanup of Rocky Flats.

When developing the current RSAL in 1996 DOE, EPA and CDPHE used the draft EPA Radiation Site Cleanup Regulation, 40 CFR 196, as the basis for the action level. At that time, EPA had only announced its intent to propose this regulation; it had not been finalized. However, since all three parties anticipated that it would be finalized and that there was nothing else in existence resembling a national standard for radiation cleanup, DOE, EPA and CDPHE believed the draft regulation was a reasonable basis for an RSAL.

40 CFR 196 stated that a radioactively contaminated site should be cleaned up such that any remaining contamination would result in a radiation dose to a member of the public

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<sup>b</sup> See, "Action Levels for Radionuclides in Soils for the Rocky Flats Cleanup Agreement", Final 10/31/1996

no greater than 15 millirem/year (mRem/yr). The draft rule went on to say that if institutional controls (i.e. legal controls that restricted Site access) were utilized to meet the 15 mRem/yr limit, the Site must, at a minimum, be cleaned up to levels that ensure individuals do not receive doses greater than 85 mRem/yr in the event the institutional controls failed (e.g. a property zoned for industrial use is later zoned for residential use).

To determine what soil action level would meet the 15/85 mRem/yr requirements of the draft rule, DOE, EPA and CDPHE used the generally accepted software program called RESRAD to calculate the amount of radioactivity in the soil that would result in a 15 mRem/yr or 85 mRem/yr dose to a future site user. In order to make that calculation, assumptions were made as to how the land will be used in the future. The assumption as to the future use of a site is one of the most important factors in assessing the risk posed by a contaminated site because a person who lives on a contaminated site will have a much higher dose than a person who occasionally visits the site. RFCA envisioned that future use of Rocky Flats would consist of commercial/light industrial activity in the southern portion of the 400-acre Industrial Area that lies at the center of the Rocky Flats property and open space/recreational activity in the surrounding Buffer Zone. Using these land-use assumptions as a guide, the parties calculated the amount of contamination that would result in a 15 mRem/yr dose to an office worker in a commercial setting and a recreational open space user. Since these two future use assumptions were predicated on the idea that legal controls would be put in place precluding other types of land use, the parties had to satisfy the second part of the draft EPA rule: that in the event those legal controls fail, future site users do not receive a dose in excess of 85 mRem/yr. It was assumed that if there were no restrictions on the use of Rocky Flats, a subdivision similar to Rock Creek would be constructed. So the parties calculated the level of contamination that would equate to an 85 mRem/yr dose to a suburban resident.

The calculated RSALs for these various scenarios are given below:

Scenario	Specific Activity Pu-239 <sup>1</sup>
15 mRem/yr Dose to Office Worker	562 pCi/g
15 mRem/yr Dose to Open Space User	4,145 pCi/g
85 mRem/yr Dose to Suburban Resident	651 pCi/g

To set an RSAL for the Industrial Area, the parties compared the office worker at 15 mRem/yr to the hypothetical future suburban resident at 85 mRem/yr, and chose the most conservative value. Similarly, for the Buffer Zone RSAL, the open space user at 15 mRem/yr was compared to the hypothetical future suburban resident at 85 mRem/yr. This is how the current RSALs of 562 pCi/g Pu-239 in the Industrial Area and 651 pCi/g Pu-239 in the Buffer Zone were chosen.

DOE, EPA and CDPHE also established a lower tier of RSALs that would trigger a different type of action than the “Tier 1 RSALs” discussed above. When contaminants

<sup>1</sup> The specific activity given is a sum-of-the-ratios number that assumes Am-241 is present and the ratio of Am-241 to Pu-239 is 0.18.

are found to exceed the Tier 1 action level, it will generally trigger an action such as removal or stabilization in place. Exceeding the Tier 2 value would generally trigger a less aggressive action which may include “hotspot” removal, capping or access restrictions. The Tier 2 RSAL for Pu-239 is based on a 15 mRem/yr dose to a suburban resident and comes out to 115 pCi/g.

## CHANGES IN THE REGULATORY LANDSCAPE

### Introduction

The EPA Radiation Sites Cleanup Regulation was never finalized, and has been officially dropped from consideration. In the meantime, another national regulation on radiation cleanup was finalized as well as some EPA policy documents on the subject. These developments called the regulatory basis for the current RSALs into question.

The RFCA parties as part of this review are considering two principal regulatory authorities as the basis for revised RSALs. These are the NRC Decommissioning Rule and the guidance and policy promulgated by the Environmental Protection Agency to implement the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA.) This paper reviews these sources at some length. For the purposes of setting an RSAL, these sources can at times be ambiguous. Both of these sources address action levels – the level of contamination that triggers a remedial action – and cleanup levels, which is the level of contamination remaining after an action has been taken. The specific charge of this review is to consider changes to RSALs, but any discussion of RSALs must also be accompanied by discussion on how ultimate cleanup levels will be determined. Both sources of new regulatory guidance address action levels and cleanup levels simultaneously.

### The NRC Rule

In 1997, the NRC promulgated a cleanup regulation (commonly referred to as the Decommissioning Rule)<sup>c</sup> which governs the cleanup of facilities that are licensed by the NRC, or by States that have had that authority delegated to them. The NRC cleanup regulation states that a site will be considered acceptable for unrestricted use if residual radioactivity, distinguishable from background, results in a dose to the average member of the critical group<sup>2</sup> no greater than 25 mRem/yr, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA). The rule goes on to say a site will be considered for license termination under restricted conditions if:

- Residual levels associated with restricted conditions are ALARA.
- The licensee has made provisions for legally enforceable institutional controls.

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<sup>c</sup> See, 10 CFR 20, subpart E.

<sup>2</sup> The term “critical group” is defined in CFR 20.1003. It means the group of individuals reasonably expected to receive the greatest exposure to residual activity for any applicable set of circumstances.

- The licensee has provided financial assurance for control and maintenance of the site.
- The licensee has prepared a “License Termination Plan” and has solicited public comment on that plan.
- Residual radioactivity at the site has been reduced so that if institutional controls were no longer in effect, members of the public will not receive a dose greater than 100 mRem/yr or, under certain circumstances, 500 mRem/yr.

The NRC does not have regulatory authority over a DOE facility such as Rocky Flats so the NRC rule is not directly applicable to Rocky Flats. However, the State of Colorado has adopted the NRC rule as a State regulation and while the rule is not applicable to Rocky Flats the State has identified the rule as relevant and appropriate<sup>d</sup>; and therefore, the substantive provisions should be used to govern the cleanup of the site. EPA and DOE agree.

Here’s how EPA, CDPHE and DOE interpret the decommissioning rule, and intend to apply the standards in the rule based upon the significant factors present at Rocky Flats:

Cleanup to levels that allow for unrestricted use are generally preferred to cleanups that result in restricted use. (Please note that at Rocky Flats, use restrictions may nonetheless be required for purposes other than limiting dose.) The rule does not explicitly require cleanup to unrestricted use, but the RFCA parties believe that an analysis of actions that would be needed to achieve unrestricted use is required.

To be acceptable for unrestricted use, the residual radioactivity levels must be "as low as reasonably achievable ("ALARA")," AND in any case may not exceed 25 mRem/yr. Put another way, if it is reasonable to achieve a level of residual contamination that results in a lower dose than 25 millirems/yr, then the rule requires the additional cleanup action.

A site may be cleaned up to less stringent levels that do not allow for unrestricted use only if the required analysis of actions to achieve unrestricted use demonstrates either (1) that the additional cleanup necessary to remove residual radioactive materials to achieve a dose that does not exceed 25 millirems per year (assuming unrestricted use) would cause net public or environmental harm, or (2) that the residual levels of contamination associated with restricted use are ALARA.

If a site is cleaned up to restricted use levels, residual contamination must be ALARA AND in no case may exceed 25 millirems per year, assuming the

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<sup>d</sup> A discussion of CERCLA’s Applicable or Relevant and Appropriate Requirements is contained in paper by Dan Miller, Colorado Attorney General’s Office, “Response to questions presented at 11/8/00 meeting”, dated November 16, 2000. Available online at [www.rfets.gov](http://www.rfets.gov), under Focus Group. 10/03/06PRE-DECISIONAL DRAFT – NOT ENDORSED BY THE DOE, EPA OR CDPHE – FOR DISCUSSION PURPOSES ONLY rev 2 4

institutional controls are in place, AND may not exceed 100 millirems per year, assuming the institutional controls fail.

The NRC rule does provide that alternative decommissioning criteria (i.e., it allows establishment of a number different from 25 mRem/year) may be established for “difficult sites with unique decommissioning problems”. Alternative criteria are allowed only in the following circumstances:

- Residual contamination is reduced to levels that are ALARA.
- The person seeking the alternative criteria has demonstrated that it is unlikely the TEDE to the average member of the critical group would exceed 100 mRem/yr; and
- Durable, enforceable institutional controls have been imposed to minimize exposures.

It is important again to emphasize the difference between a cleanup level as discussed in the NRC (and state) rule and the soil action level that is being developed by the RFCA parties. Action levels are the levels of contamination that trigger a remedial action and cleanup levels are the levels of contamination remaining after an action has been taken. In order to comply with the NRC rule as an ARAR, an analysis would be required using the ALARA concept to determine whether cleanup to unrestricted levels or to levels approaching unrestricted use is reasonably achievable for a particular remedial action.

#### CERCLA Guidance

While EPA agrees that the Decommissioning Rule is relevant and appropriate to the cleanup at Rocky Flats, it believes that the dose limits in the rule may not, in some circumstances, be sufficiently protective of human health. This concern is discussed in the EPA Guidance Document “Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination,” August 1997. This document makes the following points relevant to the RSAL debate at Rocky Flats:

Cleanup actions at Superfund sites (such as Rocky Flats) must be protective of human health and the environment and comply with applicable or relevant and appropriate requirements (ARARs).

EPA generally defines “protective of human health” as a level that represents an excess cancer risk to an individual in the range of  $10^{-4}$  to  $10^{-6}$  (1 in 10,000 to 1 in 1,000,000)

Cancer risks for radioactive contamination should generally be estimated using the slope factor methodology put forth in the EPA risk assessment manual.<sup>3</sup>

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<sup>3</sup> U.S. EPA, “Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A) Interim Final,” EPA/540/1-89/002, December 1989. U.S. EPA, “Risk Assessment Guidance for 10/03/06PRE-DECISIONAL DRAFT – NOT ENDORSED BY THE DOE, EPA OR CDPHE – FOR DISCUSSION PURPOSES ONLY rev 2

**(Please see attached memo on Radiation Risk and Dose for more information on the issues of slope factors and converting dose to risk.)**

EPA has determined that the dose limits in the NRC rule are generally not protective of human health. *The word “generally” is important here because each radionuclide has a different cancer slope factor so for some radionuclides the lifetime cancer risk associated with a 25 mRem/yr dose will be within the acceptable risk range, but for most radionuclides the risk associated with a 25 mRem/yr dose is outside the risk range.*

The NRC Rule must be met (or waived) at sites where it has been determined to be applicable or relevant and appropriate. Cleanup at these sites will typically have to be more stringent than required by the NRC dose limits. *The word “typically” is used for the same reason the word “generally” was used in the preceding paragraph.*

If a dose assessment is conducted at the site, *as was done at Rocky Flats in setting the current RSALs*, 15 mRem/yr should generally be the maximum dose limit for humans. This dose limit equates to approximately  $3 \times 10^{-4}$  (3 in 10,000) lifetime risk. **(Please see attachment 1 for discussion of how the value  $3 \times 10^{-4}$  was calculated)**

Despite these concerns, EPA expects that NRC’s implementation of the decommissioning rule will result in cleanups within the Superfund risk range at the vast majority of NRC regulated sites.

## **WHERE WITHIN THE RISK RANGE (Should a Cleanup Level Fall)?**

There is a lot of room for discussion when a range covers two orders of magnitude as the acceptable risk range does. EPA regulations and policies indicate that cleanups which result in site risks being reduced to levels anywhere within the range are acceptable. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) says the  $10^{-6}$  risk level will be used as the point of departure for determining remediation goals for alternatives when ARARs are not available. The EPA OSWER Directive 9355.0-30, Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions, states that where the cumulative carcinogenic site risk to an individual based on the reasonable maximum exposure for both current and future land use is less than  $10^{-4}$  and the non-carcinogenic hazard quotient is less than 1, action is generally not warranted unless there are adverse environmental impacts. This indicates that cleanup that reduces site risks to a level of  $10^{-4}$  is perfectly acceptable. On the other hand, the same directive says once a

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Superfund: Volume I – Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals”, EPA/540/R-92/003, December 1991.

decision has been made to take an action, the Agency has expressed a preference for cleanups achieving the more protective end of the range (i.e.  $10^{-6}$ ). In other words, if you are conducting an action to address a site risk greater than  $10^{-4}$ , explore options for reducing the risk well beyond  $10^{-4}$ . This idea is consistent with the concept of “As Low As Reasonably Achievable” (ALARA) which says that all reasonable efforts should be made to reduce potential exposure to radiation even if the regulatory safety limit is already being met.

When choosing a remedy and the risk level that remedy will achieve, EPA considers the CERCLA balancing criteria: (short-term effectiveness; long-term effectiveness and permanence; reduction of toxicity, mobility or volume through treatment; implementability; and cost), and the modifying criteria (community acceptance; and state acceptance)<sup>e</sup>. Obviously, cost and implementability are two factors that generally tend to push remedies toward the less stringent end of the risk range. The effect of the other factors may change from one case to another.

## LAND USE AND INSTITUTIONAL CONTROLS

As discussed previously, the assumptions made as to how Rocky Flats will be used in the future are very important considerations in the calculation of an RSAL. The current RSALs were developed under the assumption that the southern portion of the Industrial Area would see commercial reuse while the surrounding Buffer Zone supported open space recreation. When DOE, EPA and CDPHE were negotiating RFCA back in 1995, these two future use scenarios seemed the most likely. At that time, there was a significant level of support in the surrounding communities for these two scenarios. So the parties wrote them into the agreement. The Agencies, in drafting the RFCA, also designated certain parts of the Industrial Area as “restricted open space,” although the Agreement doesn’t really discuss the implications of that designation. Now that Senator Allard and Congressman Udall have introduced legislation that would turn Rocky Flats into a wildlife refuge, it appears a wildlife refuge worker may be the person most directly impacted by residual contamination at Rocky Flats. If the future land use assumptions change, it would probably require a revision of the RFCA.

Making decisions on the degree of cleanup based upon the anticipated future land use is consistent with EPA regulations and policy. The preamble to the National Contingency Plan (NCP)<sup>f</sup> states that the EPA will consider future land use as residential in many cases. In general, residential areas should be assumed to remain residential; and undeveloped areas can be assumed to be residential in the future unless the sites are in areas where residential land use is unreasonable. The NCP goes on to say “the assumption of future residential land use may not be justifiable if the probability that the site will support residential use in the future is small.” The EPA guidance document “Land Use in the CERCLA Remedy Selection Process,” May 25, 1995, says that in general, objectives should be developed that would achieve cleanup levels associated with the reasonably

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<sup>e</sup> See, 40 CFR 300.430(e).

<sup>f</sup> Suggest putting in citation.

anticipated future land use over as much of the site as possible. This guidance was written, at least partly, in response to criticism that EPA was too often assuming that future use of a contaminated site would be residential. Many contaminated sites being addressed in the Superfund program were industrial sites in large industrial areas that had little potential for residential redevelopment. So it was often argued that it was not cost effective for those sites to be cleaned up to a degree that would support residential use.

The NRC Decommissioning Rule does not discuss developing a cleanup level consistent with the anticipated future land use in the same way that EPA guidance does. However, the definition of the average member of the “critical group”, to which the dose rate standard applies, refers to the “applicable set of circumstances” that leads to the dose. Such circumstances include the anticipated future land use. The Preamble to the Decommissioning Rule indicates that a rural farmer future use scenario could be an “applicable set of circumstances” to calculate unrestricted use levels for an average member of the critical group in an unrestricted use scenario. The Rule says cleanup levels that allow unrestricted use are generally preferable to levels that require restricted use. DOE agrees that unrestricted use is preferable, but believes the clear intent of the rule to allow restricted use must be acknowledged and those provisions be implemented as appropriate.

If the amount of residual contamination at a site precludes unrestricted use in the future, institutional controls (legal controls) must be put in place to assure that the anticipated land use doesn’t change to an inappropriate one (e.g. residential development of property slated to be industrial). When RFCA was signed, DOE, EPA and CDPHE assumed that controls would be utilized to limit future activities on site to commercial reuse of the industrial area and recreational use of the Buffer Zone. Continued Federal ownership was one of the controls contemplated for making that assurance. Designation as a National Wildlife Refuge would assure Federal Ownership into the foreseeable future and would effectively limit the type of activities that could occur on site.

The draft EPA Radiation Sites Cleanup rule anticipated the potential failure of institutional controls when it said if institutional controls were utilized to meet the 15 mRem/yr limit, the site must be cleaned up to levels that ensure individuals are not exposed to doses greater than 85 mRem/yr in the event of institutional control failure. The Decommissioning Rule addresses the possible failure of institutional controls in a manner similar to the draft EPA rule. It says that a site will be considered for license termination under restricted conditions if, in addition to other conditions, residual radioactivity at the site has been reduced so that if institutional controls were no longer in effect, members of the public will not receive a dose greater than 100 mRem/yr or, under certain circumstances, 500 mRem/yr. The anticipation of failure is not required under the Superfund law or any of pa’s policy documents. Instead, the possibility that institutional controls can fail is addressed through the requirement that five year reviews be conducted at any site where contamination is left at levels that don’t allow for unrestricted use. Such reviews should analyze the implementation and effectiveness of institutional controls with the same degree of care as other parts of the remedy. EPA also believes emphasis must be placed on starting out with a good set of controls as discussed

in the new guidance “Institutional Controls: A Site Manager’s Guide to Identifying, Evaluating and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups,” EPA, September 2000.

It should be noted that neither DOE, CDPHE nor EPA currently envision a cleanup at Rocky Flats that would result in totally unrestricted use of the entire site. Even if cleanup of contaminated soil could be performed to a level that would allow for unrestricted use of the 6,000 plus acres, certain features would remain that would mandate institutional controls. These features include: municipal waste landfills that will be capped and left in place, a cap over the former solar evaporation ponds, at least three passive ground water treatment systems, contaminated ground water plumes and some number of detention ponds or other engineered controls for surface water.

#### **AS LOW AS REASONABLY ACHIEVABLE (ALARA)<sup>4</sup>**

The concept of ALARA has been around for many years in the worlds of nuclear power and nuclear weapons. Until recently it was primarily applied in the context of worker protection. It was employed in the planning of work and, as the name would imply, was an attempt to reduce radiation exposure as much as possible, considering factors such as the specific circumstances necessitating the exposure and the resources available. An example of the ALARA concept would be a nuclear power plant worker who needs to complete a task in an area near the fuel rod assembly. An analysis of the situation could determine that given the level of radioactivity measured in the area and the length of time necessary for the worker to complete the task, the dose to the worker from performing the task would be well below the occupational limit. The ALARA analysis would ask the question “what additional steps can be taken to further reduce the projected dose?” For example:

Is there protective clothing, beyond what is currently in use, that would reduce the worker’s dose?

Could the work be sequenced differently to allow the task to be completed quicker?

Could shielding (lead bricks) be placed between the worker and the fuel rod assembly thereby reducing exposure?

Does the worker have the best tools for the job?

Only in recent years has the concept of ALARA been used in association with environmental restoration. The Decommissioning Rule says a site will be considered acceptable for unrestricted use, if radioactivity results in a dose no greater than 25 mRem/yr, and the radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA). Thus, in addition to meeting the minimum cleanup level, all reasonable steps should be taken to reduce the contamination level even further. In

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<sup>4</sup> The regulatory definition of ALARA is found in 10 CFR 20.1003

practice this would mean that in the design of a particular cleanup project, DOE would evaluate additional measures aimed at reducing the contamination levels beyond that called for by the RSAL. Additional measures could include excavation of areas where the contamination is below the RSAL. Such an evaluation could conclude that for a relatively small increase in cost and time they could remove significant amounts of additional contamination.

Of course a key challenge in applying the ALARA process is it's inherently subjective nature; what seems reasonably achievable to one may not to another. An ALARA analysis will have to take a number of issues into consideration:

How much dose could be avoided by doing work beyond that required to meet the RSAL?

How much would the additional work cost?

Is it technically feasible?

What are the risks to workers and to the public of performing additional work?

Will natural resources/habitat be affected?

What are the offsite risks associated with additional work (e.g. risk from transportation, risks at the disposal facility).

The rules as to when you do additional work in accordance with ALARA are not hard and fast. The NRC Draft Regulatory Guide DG-4006, "Demonstrating Compliance with the Radiological Criteria for License Determination," does contain formulas for use in ALARA analyses. These formulas try to quantify the benefits of additional cleanup work by assigning a monetary amount to a unit of averted dose (e.g. the benefit of avoiding a dose of 1 Rem is given a value of \$2,000). The benefits are then compared to the cost of conducting cleanup beyond that necessary to comply with the dose standard. The NRC guidance on ALARA says that, based on NRC's analysis, additional soil cleanup will generally not be cost effective if the cleanup already meets the goal of 25 mRem/yr to an unrestricted land use scenario.

The concept of ALARA is consistent with the RFCA Vision which states where possible, the site will be cleaned up to the maximum extent feasible.

## **PROPOSED FRAMEWORK FOR RSALS AND CLEANUP DECISIONS**

With respect to the regulatory foundation upon which an RSAL will be constructed the key factors are acceptable dose and/or acceptable level of risk, future land use assumptions and ALARA.

### **Acceptable dose and/or acceptable risk.**

As previously discussed, the Decommissioning Rule is one of the key requirements that will govern the cleanup at Rocky Flats. So at a minimum the cleanup will have to reduce the contamination to meet the dose limits in the Rule. Dose assessments will be performed to calculate an RSAL that meet the 25 mRem/yr dose limit to a future user. Given the concern that the 25 mRem/yr dose limit may not be protective of human health, at least for some radionuclides, the DOE, EPA and CDPHE will also calculate RSALs based on risk, and choose the more conservative value between dose and risk. So the only way the RSAL will be based on the 25 mRem/yr dose would be if the risk associated with the dose fell within the risk range. DOE, CDPHE and EPA are considering the idea of choosing a specific value within the risk range upon which to base a RSAL. However, since we are not prepared at this time to choose a specific value, the Agencies will calculate levels of residual contamination corresponding to the risk levels of  $10^{-4}$ ,  $10^{-5}$  and  $10^{-6}$ .

## **ALARA**

In accordance with the decommissioning rule, an ALARA analysis will be required for each cleanup project. This analysis will be performed at the time the project is being designed, when all the necessary characterization data and historical information has been compiled. DOE will develop a detailed protocol for how these analyses will be conducted, in consultation with CDPHE, EPA, Local Communities and the Public, which will outline factors to be considered and how those factors will be weighted in the final analysis. This process for determining ALARA will incorporate CERCLA balancing and modifying criteria discussed earlier. The ALARA analysis will be part of the regulatory decision document for each cleanup project. The results of the analysis and the proposed action based upon the consideration of the analysis are subject to the normal decision document review and regulatory approval process. This includes consideration of any public review comments

## **Future Land Use Assumptions**

The Decommissioning Rule states that a site may be released for unrestricted use if residual radioactivity that is distinguishable from background is ALARA, and would not result in a dose in excess of 25 mRem/yr to a future user in an unrestricted scenario. The Rule says a site may be cleaned up to a less stringent level if the party performing the cleanup can demonstrate either: (1) the additional cleanup necessary to qualify for an unrestricted release would cause net public or environmental harm, or (2) the contamination levels associated with restricted use are ALARA. Thus, the RFCA Parties will consider both restricted and unrestricted scenarios in the development of RSAL and cleanup levels. The RFCA parties have chosen eight scenarios to be evaluated as shown in the table below.

The table will be completed and distributed as part of the task 3 report and will list a specific activity in pCi/g for each scenario and associated dose/risk level. The table will be used to choose an RSAL, based on an anticipated future user, and to determine the

level that represents an unrestricted future land use scenario. In addition, the table may be a useful tool in guiding stewardship and post-closure stewardship discussions and decisions.<sup>5</sup>

RSAL TABLE FOR SELECTED SCENARIOS, DOSE AND RISK				
Land Use Scenarios	25 mRem/yr	Lifetime Risk=10-4	Lifetime Risk= 10-5	Lifetime Risk= 10-6
Restricted				
Open Space User - Adult				
Open Space User - Child		-----	-----	-----
Office Worker				
Wildlife Refuge Worker				
Unrestricted Scenarios				
Suburban Resident - Adult				
Suburban Resident - Child		-----	-----	-----
Resident Rancher - Adult				
Resident Rancher - Child		-----	-----	-----

The values for this table will be calculated and distributed as part of the Task 3 Report

The open space user scenario was chosen because it is currently contemplated in the RFCA, and it is quite possible that members of the public would use the Site for open-space recreation should the site be designated a National Wildlife Refuge. The Office Worker scenario was selected because it too is currently contemplated in the RFCA; however at this time commercial reuse of the site does not appear likely. Wildlife refuge worker was chosen because this is the reasonably anticipated future user. We chose the suburban resident because we believe this is the land use that would most likely occur if the site were opened up for unrestricted use. Finally, the resident rancher scenario was chosen so the values calculated could be compared against those calculated by RAC. DOE, CDPHE and EPA do not believe the resident rancher scenario is likely as long as the Front Range is a thriving metropolitan area.

### Proposal for the RSAL and Cleanup Decisions

We propose that the RSAL be based on the reasonably anticipated land user; the refuge worker. The RSAL will be used to determine where cleanup actions will be taken at Rocky Flats. Once an action has been determined to be necessary (i.e. contamination is present in excess of the RSAL), the alternatives analysis, including application of the ALARA process, for that action will include cleanup to a level that supports unrestricted use; the suburban resident scenario. In other words, for each area of the site where contamination exceeds the RSAL, DOE will perform an evaluation to determine what level of contamination removal is reasonably achievable. While we have serious doubts that the entire site can be cleaned to unrestricted use, it is certain that such a level can be achieved for many of the contaminated areas at Rocky Flats. The first ALARA analysis will occur in conjunction with planning for the 903 pad remedial action and will give careful consideration to the issue of surface water protection.

<sup>5</sup> The RFCA Parties have not had substantive discussions on the value of retaining the existing two-tiered system for RSALs, but we may wish to discuss the issue at a future Focus Group meeting.

## **SUBSURFACE RSALS AND SURFACE WATER PROTECTION**

The RSAL we plan to develop using the framework above is meant to be protective of the anticipated future user and will only be used to address surface contamination. Calculations as to what an appropriate RSAL for buried contamination in the Industrial Area will be performed at a later time when more is known about the nature and extent of such contamination, and the possible routes of exposure. Furthermore, the proposed RSAL is not meant to be protective of the surface water standards. . Meeting the RSAL will in no way guarantee that the surface water standard won't be violated. DOE is obligated under the RCA to meet the surface water standard, and will have to take the necessary steps to do so. This could include excavation of contamination to levels below the RSAL, re-contouring of areas in and around the industrial area, stabilization measures or the construction of engineered controls. Attachment 2 illustrates many of the factors to be considered in decisions made for the protection of surface water standards.

# **New Information: Actinide Modeling and Windtunnel Tests**

**Bob Nininger  
Environmental Systems and Stewardship  
Kaiser-Hill LLC**

ADMIN RECORD



# **Actinide Modeling**

- **Wind and activities that disturb contaminated soil can result in actinide emissions to the air.**
- **Key element of future potential exposure/risk is resuspension of Pu and Am.**
- **In FY99 and FY00, modeling has been performed to examine various scenarios:**
  - **Chronic resuspension from contaminated soils, pre-and post-closure.**
  - **903 Pad Remediation**
  - **D&D of a Building with pockets of undetected contamination**
  - **Wildfire actinide emissions**

# **Actinide Modeling Results**

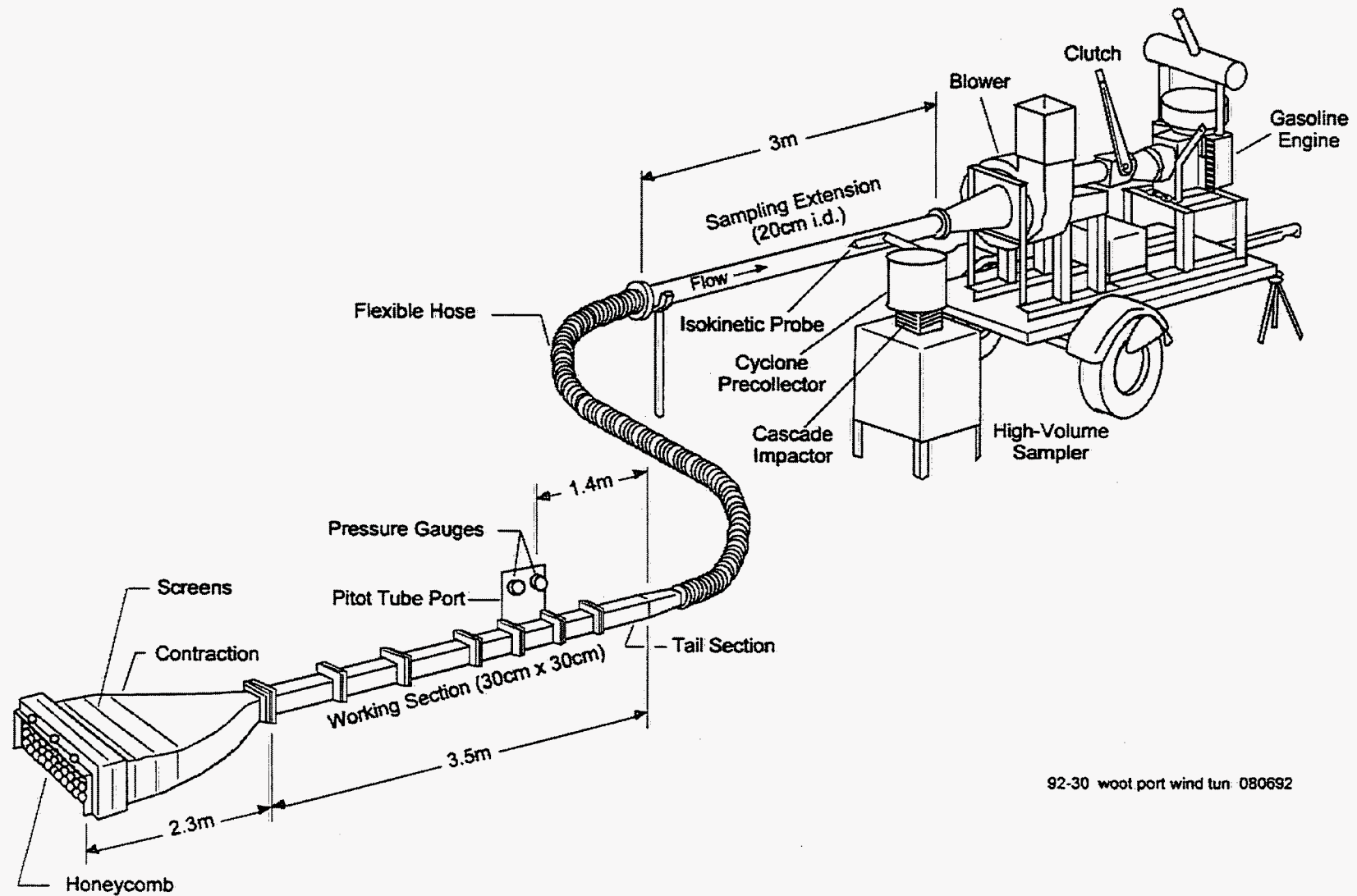
- **Modeling of chronic resuspension overpredicts air concentrations in predominant wind direction - toward Indiana.**
- **Post-D&D - Assuming cleanup to current Tier-1 levels, increased soil exposure may result in small increases in airborne concentrations**
- **During remediation of 903 Pad, emissions are not predicted in excess of protective standards.**
- **Wildfires will not result in smoke-borne Pu/Am exposures greater than protective EPA standard.**
- **Post-fire actinide concentrations in air were increased a factor of 5 compared to unburned scenario, pre-recovery.**

# **Unresolved Modeling Issues**

- **Have not modeled the contributions from exposed roadways on which there is actinide deposition.**
- **Observed soil-actinide concentrations on plants are not consistent with soil concentrations beneath plants.**
- **Site-specific resuspension factors existed only for vegetatively-covered soils; post-fire emission scenarios were not well characterized.**

**Planned prescribed Burn offered opportunity to characterize wind erosion.**

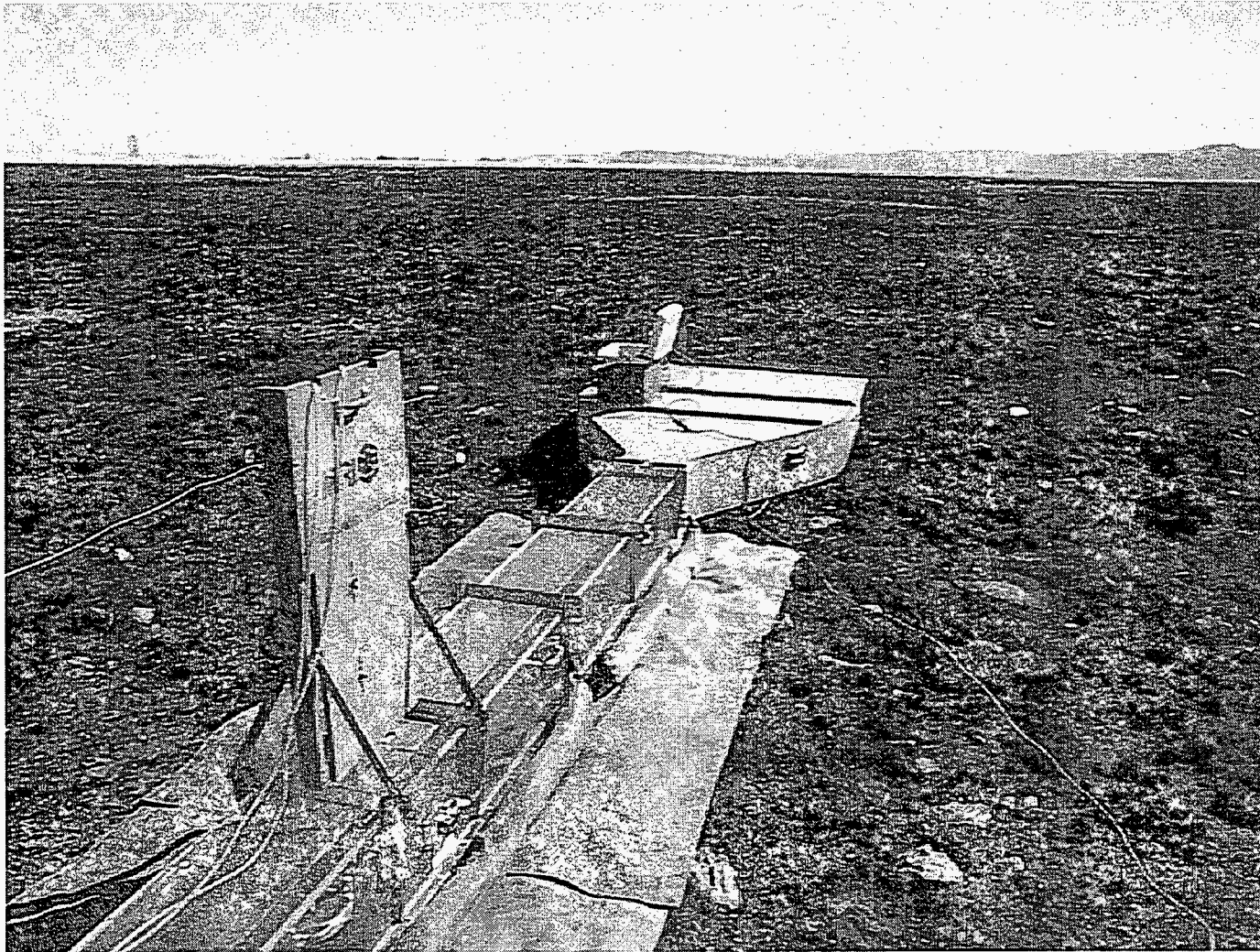
# Wind Tunnel Test Configuration



92-30 woot port wind tun 080692

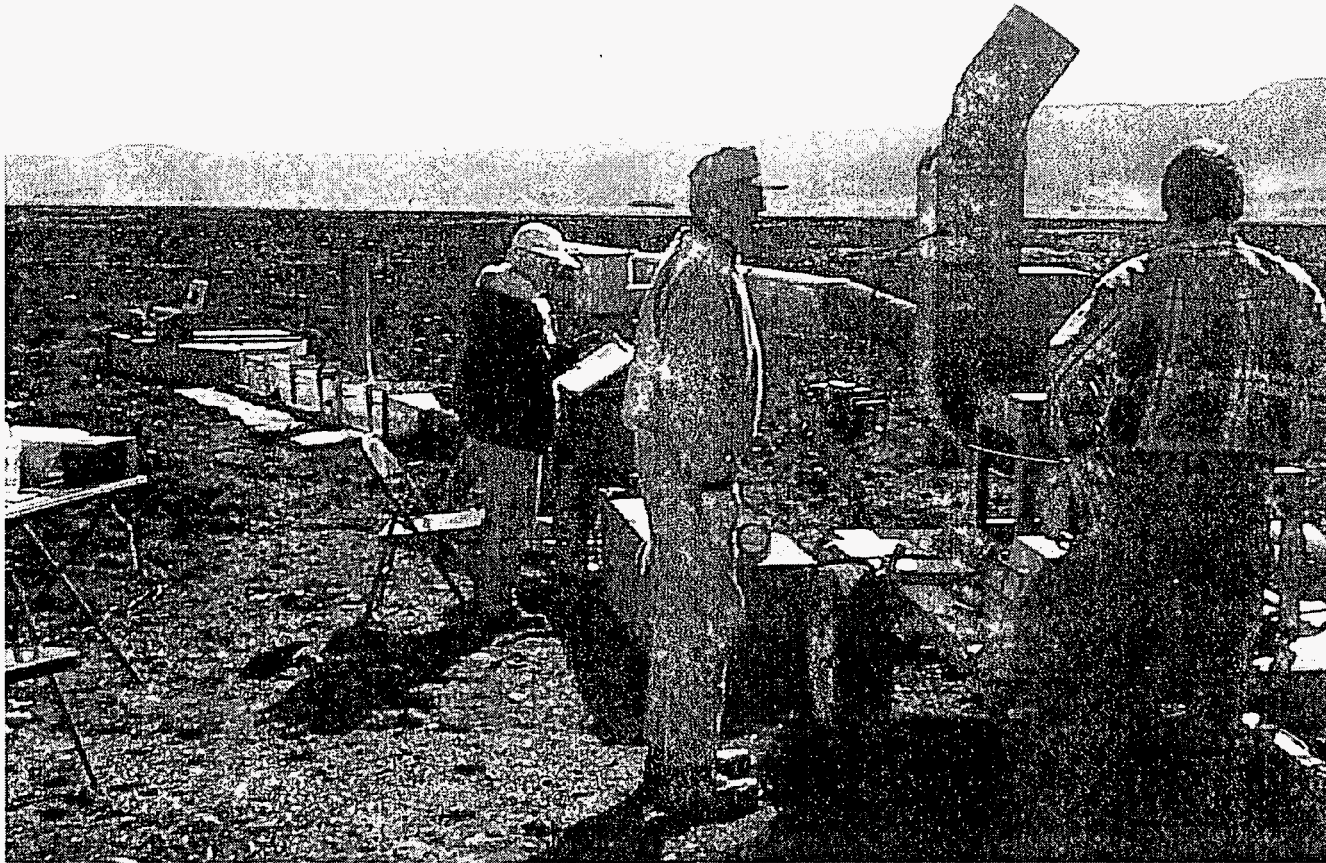
# Wind Tunnel

Prescribed Burn Site -- April 7, 2000



# Wind Erosion Testing

April 2000

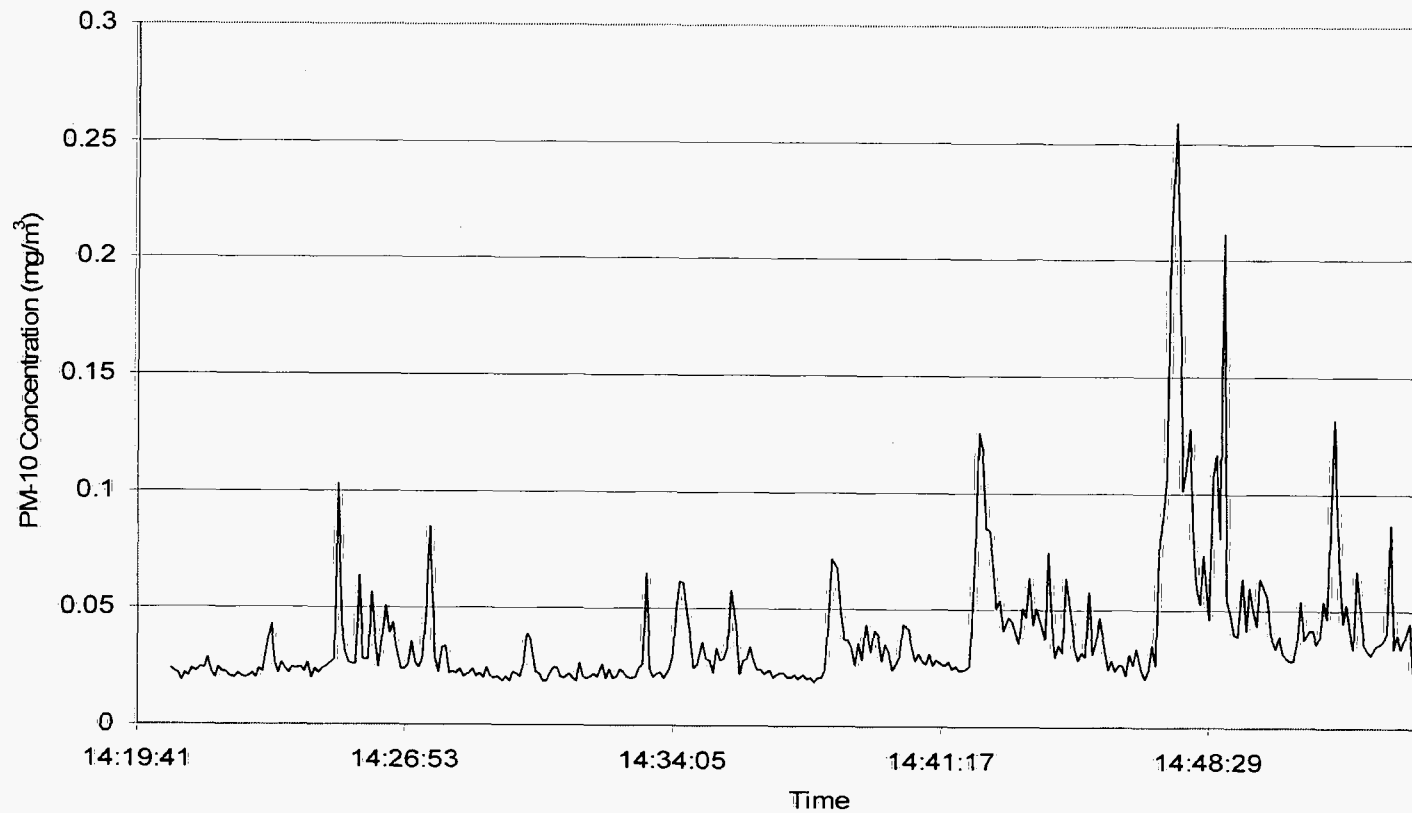


# **Wind Tunnel Test Objectives**

- **Measure Erosion Potential of burned and unburned soil plots.**
- **Observe differences in size-distribution of “burned” and “unburned” airborne dust.**
- **Measure “dustiness” of soils with different moisture content in burned and unburned areas.**
- **Determine differences in organic/elemental carbon in resuspended soils, burned and unburned.**
- **If sufficient radionuclides are present (Wildfire), compare relative activity in soil and airborne dust.**

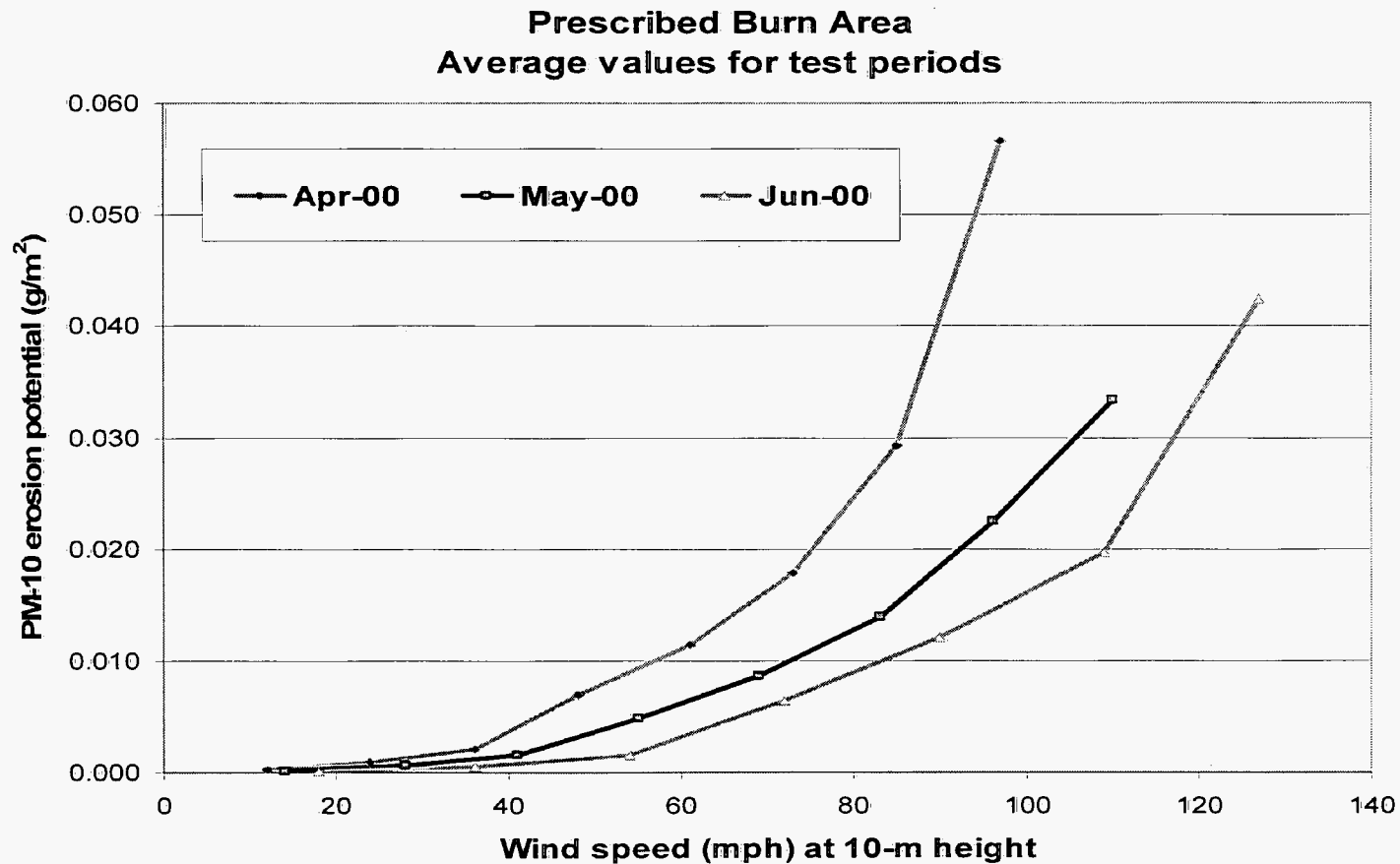
# DustTrak™ Resuspension Profile

CB-8B  
5/2/00



# PM-10 Release vs Wind Speed

## Prescribed Burn - DustTrak™ Measurements

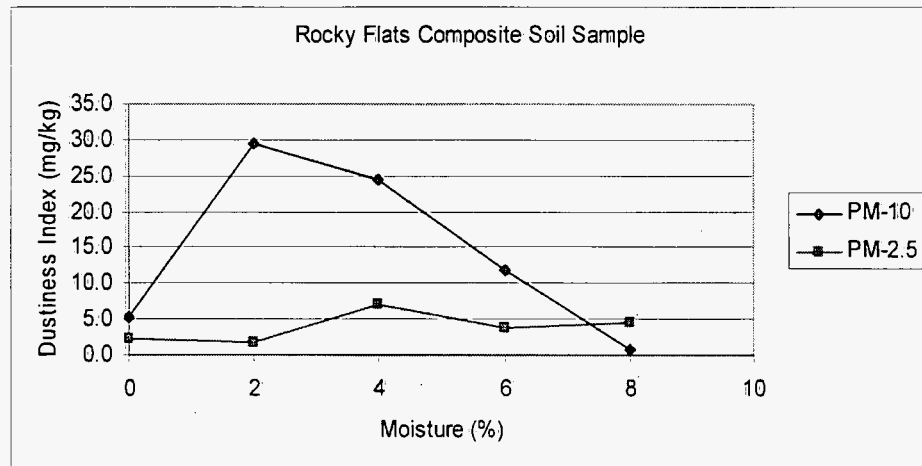
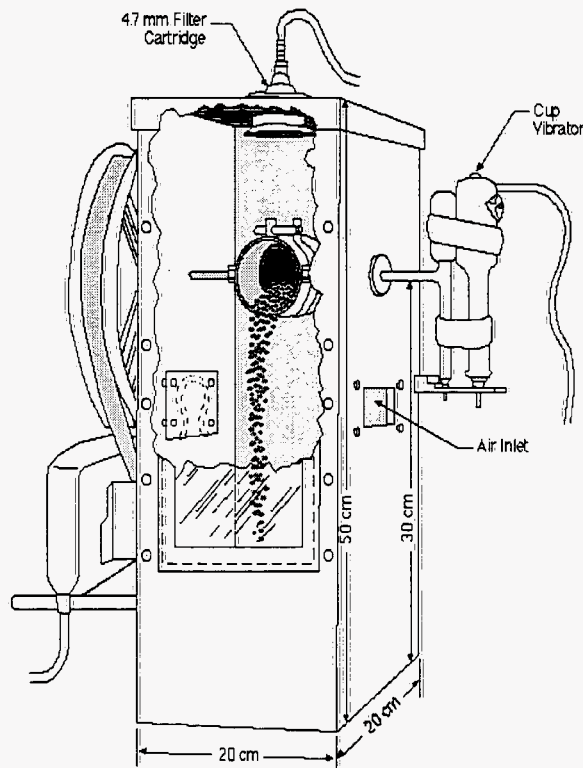


# “Dustiness Testing”

## Measure of Soil’s Tendency to Erode

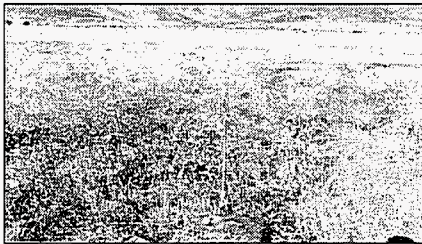
Table 1. Results of Preliminary PM-10 Dustiness Tests

Test ID	Sample label	Moisture (%)	Mass poured (g)	Mass collected (mg)	Dustiness index (mg/kg)
1	5/3 Burned Area #2	1.4	635.0	3.075	4.8
2	5/3 Burned Area #1	1.8	526.0	4.723	9.0
3	4/7 Surface Soil “D”	1.4	490.3	4.293	8.8
4	4/8 Adjacent to Plot CB-2	2.3	489.5	8.157	16.7

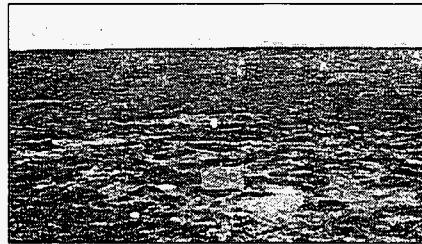


# Prescribed Burn Recovery

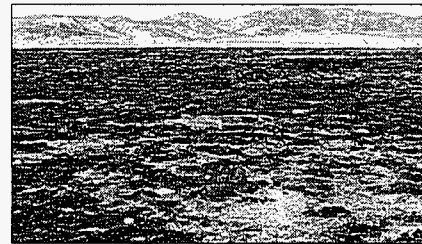
Time Series of 2000 Prescribed Burn Area at Rocky Flats Environmental  
Prescribed Burn Conducted on April 6,



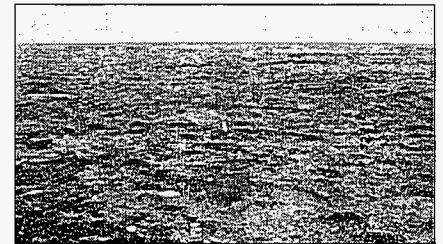
9/15/99



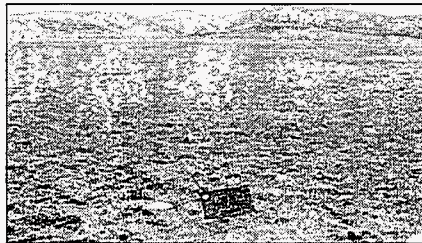
4/7/00



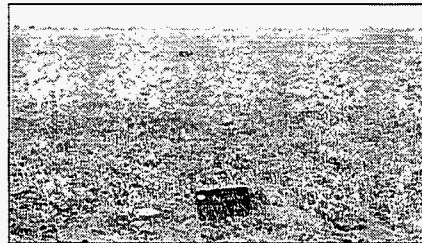
4/17/00



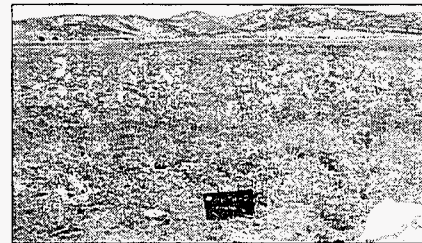
4/27/00



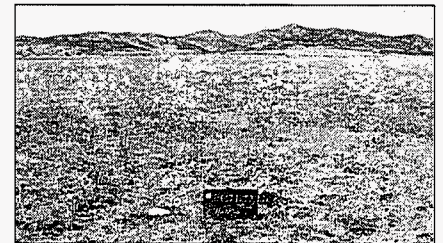
5/22/00



6/28/00



8/10/00



9/27/00

# **“Wildfire” Wind Tunnel Testing**

**Wildfire on July 10**

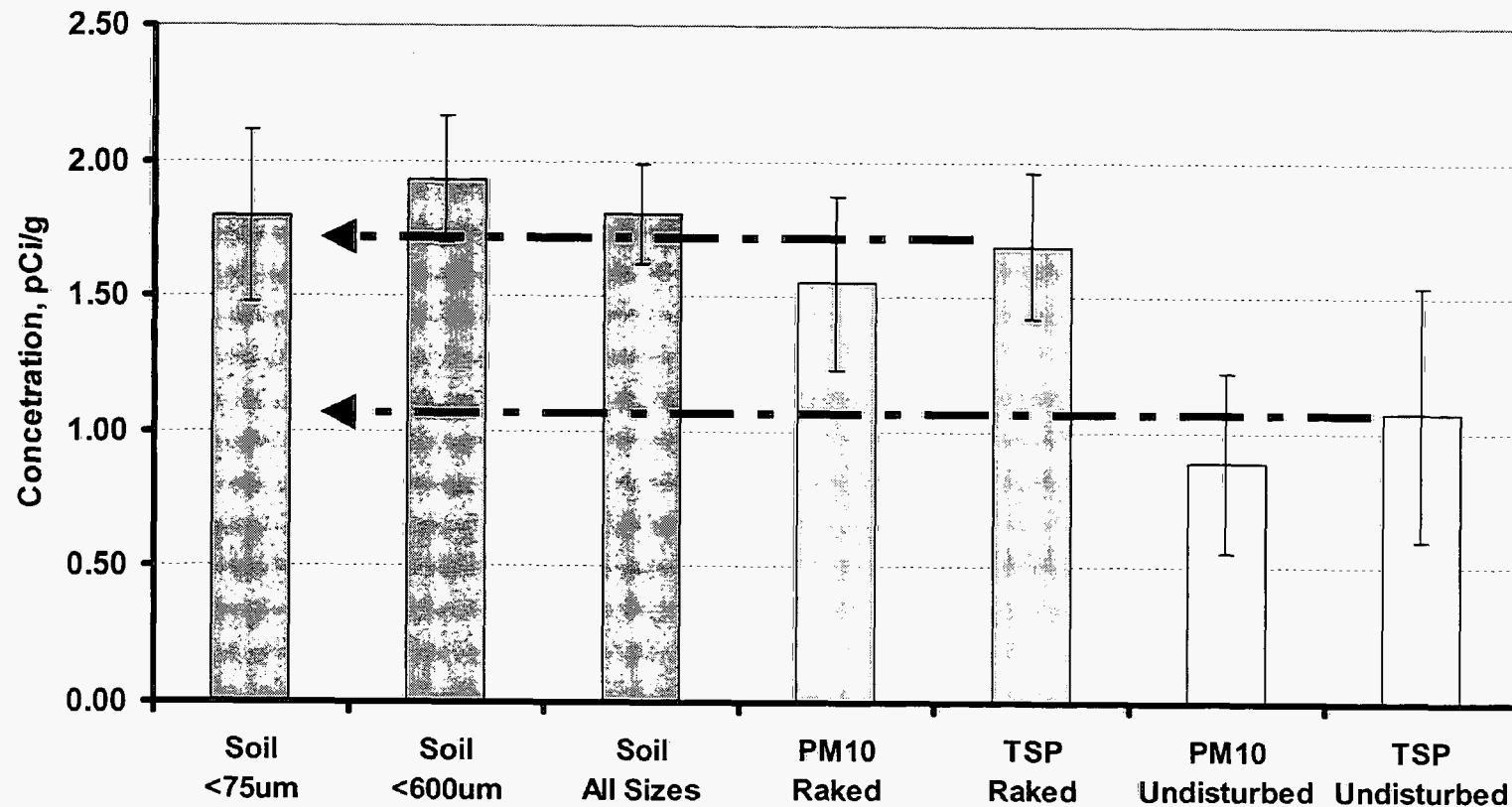
- **Same wind-tunnel tests as in Prescribed Burn.**
- **Single Test Event - no characterization of recovery associated with Wildfire.**
- **Added testing for radionuclide content in soil and in airborne dust.**

# **Radionuclide Tests**

- **Soil activity in “Wildfire” Area was known prior to the event - 2 to 5 pCi/g for plutonium.**
- **Provided opportunity to compare distribution of radionuclide activity in soil with comparable activity in airborne dust.**

# Activity Distribution -

## An Observation in "Wildfire" Burned Area



# **Path Forward**

- **Analyze results of wind-tunnel tests**
- **Integrate results with information already known regarding wind erosion at RFETS**
- **Model Post-fire Scenarios using wind-tunnel information and site observations:**
  - **Episodic nature of wind events**
  - **Limited erodible-soil reservoir**
  - **Wind-speed dependence**
  - **Distribution of actinides**
  - **Increased erosion potential related to fires**

## RFCA Stakeholder Focus Group Actions / Issues Database

Record No.	Requested By	Date Due	Date Complete	Completed By
<hr/>				
3		9/27/00		
Derivation of 140 pCi/l PPRG (from 1996 IGD document, now 21 pCi/l) for onsite surface water, including risk basis.				
7	DOE	9/20/00		
Reed Hodgkin to call Goldfield to ask his reaction of the answers submitted to his 903 Pad documents.				
1	Joe Goldfield	9/13/2000	9/13/00	Steve Paris to Christine Bennett
Response to Joe Goldfield's submission re: Pu calculation in 903 pad area				
17	Focus Group	08/30/2000	08/30/2000	Troy Timmons
Contract language concerning onsite water quality				
18	Focus Group	08/30/2000	08/30/00	John Rampe
Surface Water Quality at Rocky Flats: Implications for Cleanup				
19	Focus Group	8/30/00	08/30/2000	Russell McAllister
Actinide Migration Evaluation Erosion and Sediment Modeling Project: Summary of Findings				
2	Dave Shelton	08/30/2000		
Confirm total and maximum Am241 / Pu239/240 values for station GS03 as shown in Appendix D-3 of the 8/30/00 packet to Victor Holm.				
20		8/30/00	08/30/2000	Richard DiSalvo
RFCA Radionuclide Soil Action Level Tier I and Tier II Concept				
36	Focus Group	09/13/2000	09/13/2000	Bob Nininger, John Stover
Preliminary water balance estimates				
37	Focus Group	09/13/2000	09/13/2000	John Stover
Description of the basis of the 30-day water quality standard				
38	Focus Group	09/13/2000	09/13/2000	Diane Niedzwiecki
Risk basis for 0.15 pCi/l water quality standard				
8		09/22/2000	09/22/2000	Russell McCallister
Map showing areas of site where water quality will drive cleanup				
34	Focus Group member	09/27/2000	09/27/2000	Agencies
How the Focus Group input is directly or indirectly affecting policy decisions concerning clean up at RFETS.				

ADMIN RECORD

## **RFCA Stakeholder Focus Group Actions / Issues Database**

35

Reed Hodgin

Ongoing

Agencies

Agencies to propose long-term path for the Focus Group, identifying key policy questions that the agencies plan to answer in the future with Focus Group input.

## RFCA Stakeholder Focus Group Actions / Issues Database

Record No.	Requested By	Date Due	Date Complete	Completed By
<hr/>				
<b>Action / Issue</b>				
40	Focus Group	09/27/2000		
Laboratory quality analysis, including a more thorough explanation of the alternatives and criteria.				
41	Focus Group	09/27/2000		
Include in the laboratory quality analysis the methodology of treating negative concentration results in 30-day averages.				
42	Focus Group	10/11/2000	10/11/2000	Carl Spreng
Surface water quality standards at other DOE sites				
21		11/08/2000		
Research the last vegetation study completed for the RFETS, including vegetation uptake of radionuclides.				
22	Dave Abelson	01/03/2001		
A key conversation in the 11/29/00 RFCA Focus Group Meeting Minutes wasn't captured: the whole discussion of the NRC rule is geared towards the goal of unrestricted clean-up. Where it's mentioned on page 7 of the minutes, it gives the wrong impression.				
23	Dave Abelson	01/03/2001		
On page 8 of the 11/29/00 RFCA FG Meeting Minutes, the first question didn't really capture the flavor of what we were discussing; i.e., the NRC rule has capability as an ARAR to determine soil action levels (SALs), but it also has the capability to question the final clean-up levels. That needs to be filled out more.				
24	Mary Harlow	01/03/2001	01/10/2001	Christine Bennett
There's a question mark at the bottom of page 7 of the 11/29/00 RFCA FG Meeting Minutes which leaves the sentence incomplete.				
26	LeRoy Moore	01/03/2001		Agencies
Need to calculate RSALs based on both risk and dose, then adopt the more restrictive result.				
27	Focus Group			
Briefing on and discussion of dose conversion factors and slope factors as a special topic in a future meeting.				
28	Focus Group	1/17/01		
Does DOE have source code from Argonne for RESRAD Version 6.0?				
29	DOE	Ongoing	Ongoing	Focus Group
5-year review of CERCLA requirement will initiate periodic reassessments of the cleanup. The 5 years may not be rapid enough. Need to discuss in a future meeting				
30	Focus Group			

## **RFCA Stakeholder Focus Group**

### **Actions / Issues Database**

Importance of understanding the sensitivity of the RESRAD model to inputs and pathways, especially as related to air resuspension. This is DOE's model of choice pending results of the air resuspension review. (12/13/00 meeting minutes)

## RFCA Stakeholder Focus Group Actions / Issues Database

Record No.	Requested By	Date Due	Date Complete	Completed By
<hr/>				
<b>Action / Issue</b>				
31	Focus Group			
Verify that the dose conversion factors used in the RESRAD model are appropriate. (12/13/00 meeting minutes)				
32	Focus Group			
Discussion of whether to use ICRP 30 or ICRP 72 factors in the RESRAD model evaluation. (12/13/00 meeting minutes)				
33	Jerry Henderson	01/17/2001		
Answer the question: Is the Wednesday afternoon conference call necessary for the RSALs Review meetings? Bring up as item on 1/17/01 RFCA Focus Group meeting.				

## RFCA Stakeholder Focus Group Attachment C

Title: Focus Group Issues / Questions Database

Date: January 12, 2001

Author: Christine Bennett  
AlphaTRAC, Inc.

Phone Number: (303) 428-5670

Email Address: cbennett@alphatrac.com

ADMIN RECORD

~~37~~

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# **Evaluation of the Area Factor Used in the RESRAD Code for the Estimation of Airborne Contaminant Concentrations of Finite Area Sources**

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**Environmental Assessment Division  
Argonne National Laboratory**



Operated by The University of Chicago,  
under Contract W-31-109-Eng-38, for the

**United States Department of Energy**

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SW-2-198

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Argonne, Illinois 60439-4815  
Telephone (630) 252-3107

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## **Evaluation of the Area Factor Used in the RESRAD Code for the Estimation of Airborne Contaminant Concentrations of Finite Area Sources**

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by Y.-S. Chang, C. Yu, and S.K. Wang\*

Environmental Assessment Division,  
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

July 1998

Work sponsored by U.S. Department of Energy, Assistant Secretary for Environment, Safety and Health,  
Office of Environmental Policy and Assistance, and Assistant Secretary for Environmental Management,  
Office of Environmental Restoration

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\* S.K. Wang is currently associated with Kaohsiung Institute of Technology, Kaohsiung, Taiwan

## CONTENTS

NOTATION .....	v
ABSTRACT .....	1
1 INTRODUCTION .....	1
2 PROPOSED AREA SOURCE CONCENTRATION MODEL .....	3
3 RESULTS AND DISCUSSION .....	13
4 SENSITIVITY ANALYSIS .....	21
5 SUMMARY AND DISCUSSION .....	25
6 REFERENCES .....	26

## FIGURES

1 Representation of Area and Line Sources .....	4
2 Relative Ground-Level Concentrations for $L = 1,000$ m and $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	6
3 Relative Ground-Level Concentrations for $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	15
4 Relative Effective Source Strength and Percent Deposited over the Area Source for $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	17
5 Area Factors for $D_p = 1, 2, 5, 10, 15, \text{ and } 30 \mu\text{m}$ .....	18
6 Relative Area Factors Associated with Perturbation of Rainfall Rate for $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	22
7 Relative Area Factors Associated with Perturbation of Particle Density for $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	23
8 Relative Area Factors Associated with Perturbation of Stability Class for $D_p = 1, 10, \text{ and } 30 \mu\text{m}$ .....	24

## TABLES

1	Parameters Used to Calculate Pasquill-Gifford $\sigma_y$ .....	10
2	Parameters Used to Calculate Pasquill-Gifford $\sigma_z$ .....	11
3	Parameter Values Used to Estimate Airborne Concentrations and Area Factors .....	14
4	Coefficients Derived for the Least Square Regression Curves for Area Factors .....	20

## NOTATION

The following is a list of the acronyms and abbreviations, including units of measure, used in this report. Acronyms and abbreviations used only in equations, tables, or figures are defined in the respective equations, tables, or figures.

### ACRONYMS AND ABBREVIATIONS

AMAD	activity median aerodynamic diameter
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
NOAA	National Oceanic and Atmospheric Administration
RESRAD	<u>residual</u> <u>radioactive</u> material code

### UNITS OF MEASURE

cm	centimeter(s)
g	gram(s)
kg	kilogram(s)
m	meter(s)
m <sup>2</sup>	square meter(s)
m <sup>3</sup>	cubic meter(s)
μm	micrometer(s)
s	second(s)
yr	year(s)
°C	degree(s) Celsius

# **EVALUATION OF THE AREA FACTOR USED IN THE RESRAD CODE FOR THE ESTIMATION OF AIRBORNE CONTAMINANT CONCENTRATIONS OF FINITE AREA SOURCES**

by

Y.-S. Chang, C. Yu, and S.K. Wang

## **ABSTRACT**

The "area factor" is used in the RESRAD code to estimate the airborne contaminant concentrations for a finite area of contaminated soils. The area factor model used in RESRAD version 5.70 and earlier (referred to as the "old area factor") was a simple, but conservative, mixing model that tended to overestimate the airborne concentrations of radionuclide contaminants. An improved and more realistic model for the area factor (referred to here as the "new area factor") is described in this report. The new area factor model is designed to reflect site-specific soil characteristics and meteorological conditions. The site-specific parameters considered include the size of the source area, average particle diameter, and average wind speed. Other site-specific parameters (particle density, atmospheric stability, raindrop diameter, and annual precipitation rate) were assumed to be constant. The model uses the Gaussian plume model combined with contaminant removal processes, such as dry and wet deposition of particulates. Area factors estimated with the new model are compared with old area factors that were based on the simple mixing model. In addition, sensitivity analyses are conducted for parameters assumed to be constant. The new area factor model has been incorporated into RESRAD version 5.75 and later.

## **1 INTRODUCTION**

The U.S. Department of Energy (DOE) residual radioactive material code (RESRAD) is a computer code developed at Argonne National Laboratory to calculate the radiological dose to which a hypothetical on-site resident or worker would be exposed when the soil over a particular site is radiologically contaminated (Yu et al. 1993). Various exposure pathways are considered in the RESRAD code, including the inhalation of contaminated airborne particulates. For an on-site receptor, the contaminated dust resulting from on-site activities such as mechanical disturbance or natural wind erosion would be diluted because of mixing with uncontaminated off-site dust. The

degree of dilution depends primarily on the soil characteristics and atmospheric conditions for the area of concern. For the inhalation and foliar deposition pathways in the RESRAD code, the fraction of the total ambient airborne particulate concentration that originates from the contaminated site is estimated from the monitored ambient particulate concentration data at the site or at a nearby location. This estimation involves the use of a parameter called the "area factor," which is defined as the ratio of the airborne concentration from a finite area source to the airborne concentration of an infinite area source. The area factor is less than or equal to unity because the airborne particulate concentration from a finite area source is always lower than that from an infinite area source. For example, for larger particles with high gravitational settling velocity under weak wind, emission sources upwind of some point within a square area source fail to contribute to a receptor at the downwind boundary of the site. In this case, the area factors for the area larger than the one mentioned become unity.

The area factor depends on wind speed and direction, location of receptor, particle size distribution, dry and wet deposition, and other atmospheric conditions. The area factor used in RESRAD version 5.70 and earlier, which was derived from a simple mixing model, depends only on the size of the contaminated surface area and fails to reflect any site-specific characteristics. To introduce important site-specific characteristics into the model, an alternative area factor formulation is presented. The new formulation is based on the concept of integrating airborne particulate contributions from multiple line sources that represent the area source, assuming the dispersion of the line source emissions as Gaussian. Site-specific parameters considered in the new formulation include average wind speed, the size of the contaminated site, and average particle size. The first two parameters are already incorporated into the RESRAD input database.

## 2 PROPOSED AREA SOURCE CONCENTRATION MODEL

To calculate for on-site receptor locations the airborne concentrations of particulate emissions from a contaminated site, the site is assumed to be a square area divided into a series of line sources oriented perpendicular to the wind direction (Figure 1). The receptor  $R_j$ , which is the basis for model formulation throughout this section, is assumed to be located at the center of the downwind edge of the contaminated site. The airborne concentration ( $\chi_A$ , measured in grams per cubic meter) at the downwind receptor  $R_j$  in Figure 1 resulting from the square area source can be estimated by combining concentration contributions from  $N$  line source segments as follows:

$$\chi_A = \sum_{i=1}^N \chi_{Li} \quad (1)$$

If each line source is situated on the  $y$ -axis (which moves with a line source being evaluated), airborne concentrations from the  $i^{th}$  line source emission at the downwind receptor  $R_j$  can be calculated. The calculation is based on the generalized crosswind finite line source Gaussian formulation (Turner 1970, 1994) as follows:

$$\chi_{Li}(x, 0, z; H_e) = \frac{q_{Li}^{eff}}{\sqrt{2\pi}u\sigma_z} \left\{ \exp\left[-\frac{(z-H_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H_e)^2}{2\sigma_z^2}\right] \right\} \cdot \int_{-L/2\sigma_y}^{L/2\sigma_y} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{p^2}{2}\right) dp \quad (2)$$

where

$\chi_{Li}(x, 0, z; H_e)$  = concentration ( $\text{g}/\text{m}^3$ ) at a receptor  $R_j(x, 0, z)$  resulting from the  $i^{th}$  line source with an effective release height  $H_e$  (m);

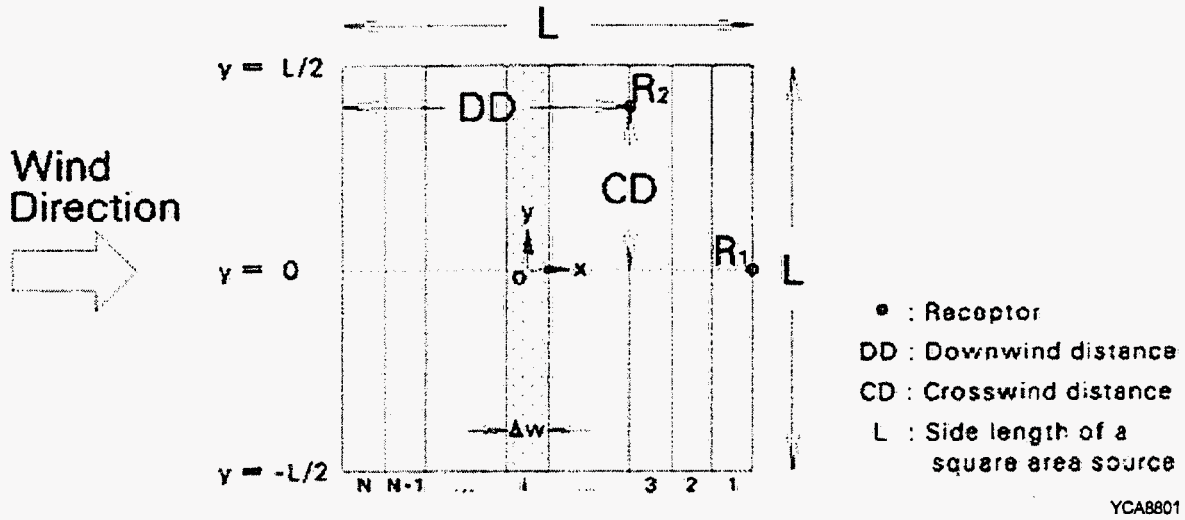
$q_{Li}^{eff}$  = effective line source strength [ $\text{g}/(\text{m}\cdot\text{s})$ ];

$u$  = mean wind speed at effective release height (m/s);

$\sigma_y, \sigma_z$  = standard deviation of lateral, vertical concentration distribution (m);

$p = y/\sigma_y$ ; and

$L$  = side length of square area source (m).



**FIGURE 1 Representation of Area and Line Sources**

To account for the gravitational settling of particulates, the effective release height of emission  $H_e$  in Equation 2 is replaced by the term  $(H_e - H_v)$ , where  $H_v = v_g x/u$  and with  $v_g$  being the gravitational settling velocity. This substitution tilts the axis of the plume downward at an angle of  $\tan^{-1}(v_g/u)$ . (The effects of gravitational settling are further discussed later in this section.) The value of the integral in Equation 2, an area under the Gaussian curve, is determined with a fifth-order polynomial approximation (Abramowitz and Stegun 1964). If lower and upper limits in the integral approach  $-\infty$  and  $+\infty$ , respectively, then the integral yields unity. Also, the particulate emission of concern is considered a ground-level or near-ground-level, nonbuoyant release; therefore, the contribution of reflection of the plume is relatively smaller at the top of the mixing layer than at the surface. In fact, this is not true for an extremely unstable condition (e.g., Pasquill Stability Class A) when vigorous vertical mixing occurs; however, over a long-term period, this condition accounts for far less time than the sum of other stability conditions. Accordingly, for simplicity, the reflection of the plume at the top of the mixing layer is not considered in this study.

The area source strength,  $q_A$ , at the point of emission will gradually decrease through dry deposition and rain scavenging as the plume disperses downwind. To account for the source depletion with downwind distance, the effective line source strength at the downwind receptor  $R_i$  of particles emitted from the  $i^{th}$  line source shown in Figure 1 can be approximated as

$$q_{Li}^{eff} = q_{Ai}^{eff} \cdot \Delta w = [q_A - \sum_{i=1}^i (F_{Di} + F_{Wi})] \cdot \Delta w \quad , \quad (3)$$

where

$q_{Ai}^{eff}$  = effective area source strength at the downwind receptor  $R_i$   
[g/(m<sup>2</sup> · s)];

$\Delta w$  = width of a line source, defined as the side length of square area  
source divided by the total number of line sources (m);

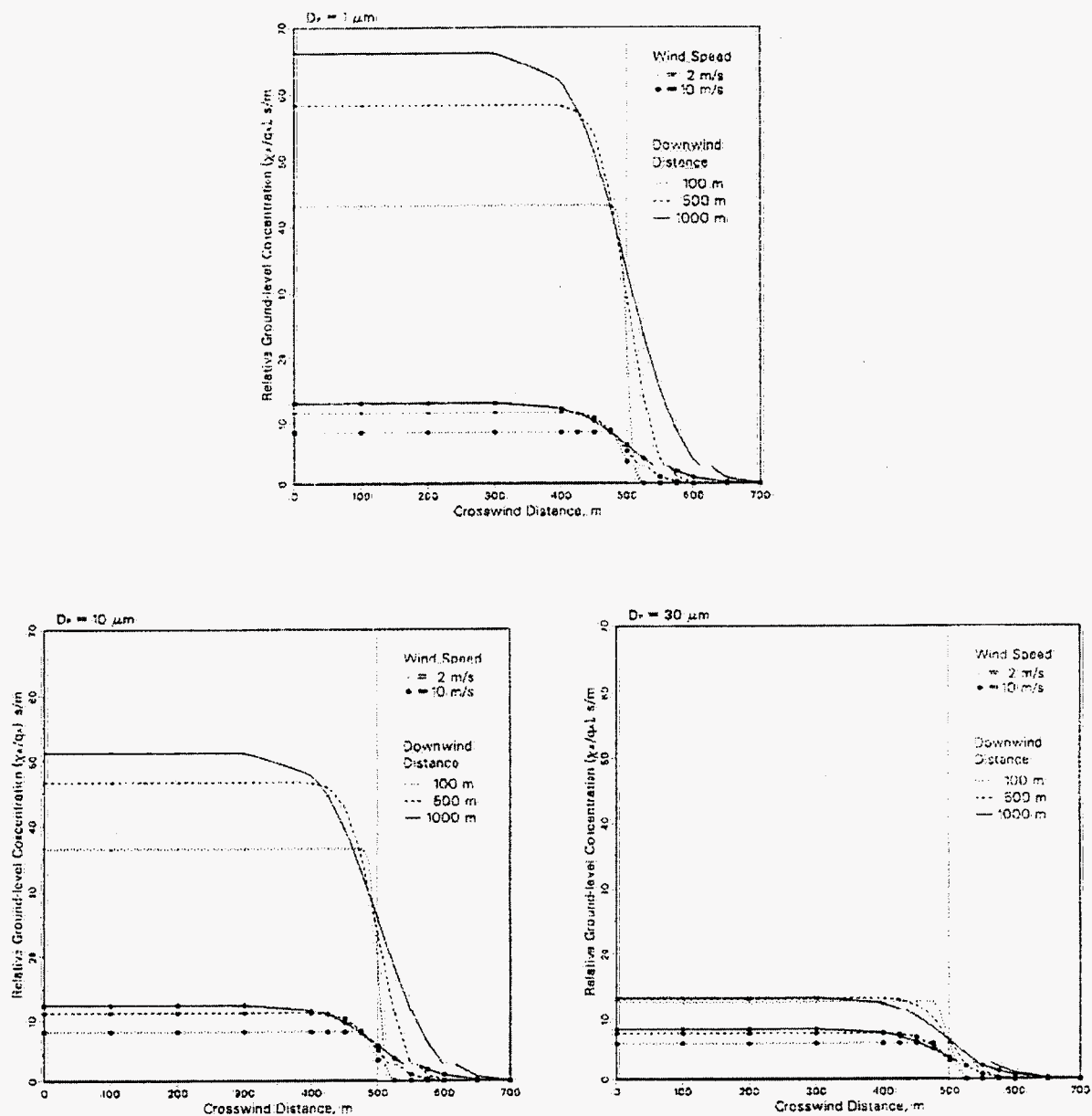
$q_A$  = area source strength at the point of emission [g/(m<sup>2</sup> · s)]; and

$F_{Di}, F_{Wi}$  = mass flux by dry and wet deposition on the surface of crosswind  
distances including downwind receptor  $R_i$  of the  $i^{th}$  line source  
[g/(m<sup>2</sup> · s)].

Mass fluxes  $F_{Di}$  and  $F_{Wi}$  can be estimated by integrating products of local concentration and deposition velocities from  $-\infty$  to  $\infty$  in the y direction. These fluxes can be approximated by multiplying the concentration at the center of the downwind edge by the deposition velocity, because the crosswind concentration profile forms a bell shape with a flat top, as shown in Figure 2. Also note that the concentration from an infinite area source should approach a finite value; the concentration from a finite area source is divided by this finite value to determine the area factor. Accordingly, in this study, the effective source strength concept as shown in Equation 3 was adopted rather than the source exponential decay term, which fails to approach zero until the downwind distance goes to infinity. Formulations for deriving dry and wet deposition fluxes  $F_D$  and  $F_W$  are discussed below.

In nature, air pollutants are ultimately removed from the atmosphere by (1) dry and/or wet deposition mechanisms onto the ground surface or (2) radioactive decay or chemical transformation while being transported downwind. In this study, only dry and wet deposition are considered, and the loss of material from the plume is approximated by assuming that the source strength decreases because of dry and wet deposition. Dry deposition of an airborne material onto the earth's surface can be caused by a combination of several natural processes, such as gravitational settling, inertial impaction, molecular and turbulent diffusion, and ground absorption (by soil, water, buildings, or vegetation). The dry deposition velocity is predicted to depend on particle density, friction velocity, and surface roughness. In general, large particles ( $D_p > 10 \mu\text{m}$ ) are deposited predominantly by gravitational settling, whereas very small particles ( $D_p < 0.1 \mu\text{m}$ ) are deposited mainly by Brownian diffusion. In this study, particles ranging from 1 to 30  $\mu\text{m}$  in diameter are of interest; therefore, only the gravitational settling process is considered. Then, the rate of dry deposition as a result of gravitational settling,  $F_{Di}$  [g/(m<sup>2</sup> · s)], is given by

$$F_{Di}(x, z_d) = v_g \cdot \chi_{Li}(x, 0, z_d; H_e) \quad , \quad (4)$$



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FIGURE 2 Relative Ground-Level Concentrations for  $L = 1,000 \text{ m}$  and  $D_p = 1, 10, \text{ and } 30 \mu\text{m}$

where

$v_g$  = gravitational settling velocity (m/s); and

$\chi_{Li}(x,0,z_d;H_e)$  = concentration (g/m<sup>3</sup>) at a reference height  $z_d$  (m) above the surface.

For particles that follow the Stokes law, the terminal gravitational settling velocity  $v_g$  (m/s) can be expressed as

$$\frac{v_g}{18 \mu_a} = \frac{\rho_p g D_p^2}{18 \mu_a} \quad (5)$$

where

$\rho_p$  = particle density (kg/m<sup>3</sup>),

$g$  = gravitational acceleration (9.8 m/s<sup>2</sup>),

$D_p$  = particle diameter (m), and

$\mu_a$  = absolute viscosity of air at sea level and 15°C [ $1.7894 \times 10^{-5}$  kg/(m · s)].

Airborne particulates are also removed by wet deposition mechanisms, including rainout (in-cloud scavenging) and washout (below-cloud scavenging by falling rain, snow, etc.). In this study, only the washout process is considered. In many cases, the local rates of removal of particulates by wet deposition, in g/(m · s), can be represented as a first-order process:

$$\text{Local rate of removal} = \Lambda(D_p; z) \cdot \chi_{Li}(x,0,z;H_e) \quad (6)$$

where  $\Lambda(D_p; z)$  = washout coefficient (s<sup>-1</sup>). This first-order representation means that the scavenging is irreversible; that is, the rate of removal depends linearly on the airborne concentration and is independent of the quantity of material scavenged previously. The wet deposition flux is the sum of wet removal from all volume elements aloft, assuming that the scavenged materials fall down as precipitation. Similar to dry deposition, the rate of wet deposition,  $F_{wi}(x, z_d)$  in g/(m<sup>2</sup> · s) can be given by

$$F_{wi}(x, z_d) = \int_0^H \Lambda(D_p; z) \cdot \chi_{Li}(x,0,z;H_e) dz = v_w \cdot \chi_{Li}(x,0,z_d;H_e) \quad (7)$$

where

$H$  = average traveling distance of a raindrop (m), and

$v_w$  = wet deposition velocity (m/s).

To formulate the wet deposition velocity,  $v_w$ , monodisperse raindrop size is assumed for simplicity. First, the number of raindrops falling onto the ground,  $N_r$  [number of droplets/(m<sup>2</sup> · s)], can be given by

$$N_r = 6.056 \times 10^{-10} \cdot R / D_r^3, \quad (8)$$

where

$R$  = annual rainfall rate (cm/yr), and

$D_r$  = diameter of a raindrop (m).

Also, the total mass of airborne particulates swept out by each raindrop,  $M$  (g), can be approximated by

$$M = A \cdot H \cdot \chi_{Li}^{av}(x, 0; H_e), \quad (9)$$

where

$A$  = cross-sectional area of a raindrop, given by  $\pi D_r^2/4$  (m<sup>2</sup>); and

$\chi_{Li}^{av}(x, 0; H_e)$  = average airborne concentration in the volume swept by a raindrop (g/m<sup>3</sup>).

This equation implies that all particles in the geometric volume swept out by a falling raindrop will be collected by the raindrop; that is, the value of the collection efficiency between droplets and particles is unity. Accordingly, combining Equations 8 and 9, the total flux,  $F_{wi}$  [g/(m<sup>2</sup> · s)], can be given by

$$F_{wi}(x, z_d) = 4.756 \times 10^{-10} \cdot R \cdot H \cdot \chi_{Li}^{av}(x, 0; H_e) / D_r. \quad (10)$$

It is reasonable to assume that the precipitation scavenging takes place from the point of  $3\sigma_z$ , where the concentration is approximately 1% of that of the plume centerline, to the surface. For convenience, the plume height,  $PH$ , to account for plume tilting is defined as

$$PH = 3\sigma_z - v_g \cdot x / u. \quad (11)$$

Then,  $\chi_{Li}^{av}$  can be expressed in terms of  $\chi_{zd}$  in Equation 7:

$$\chi_{Li}^{av}(x,0;H_e) = \frac{\chi_{Li}(x,0,z_d;H_e) \int_0^{PH} [\exp(-\frac{p_1^2}{2}) + \exp(-\frac{p_2^2}{2})] \cdot dz}{PH \cdot [\exp(-\frac{q_1^2}{2}) + \exp(-\frac{q_2^2}{2})]} , \quad (12)$$

where

$$p_1 = (z - H_e + H_v)/\sigma_z,$$

$$p_2 = (z + H_e - H_v)/\sigma_z,$$

$$q_1 = (z_d - H_e + H_v)/\sigma_z, \text{ and}$$

$$q_2 = (z_d + H_e - H_v)/\sigma_z.$$

As in Equation 2, the value of the integral can be calculated with a fifth-order polynomial approximation. Combining Equations 11 and 12 into Equation 10, the rate of wet deposition can be rewritten in terms of wet deposition velocity  $v_w$  and concentration at the reference height  $z_d$ , as in the calculation for dry deposition.

Lateral and vertical dispersion coefficients  $\sigma_y$  and  $\sigma_z$  are estimated on the basis of the formulae used in the Industrial Source Complex model (EPA 1995). Equations that approximately fit the Pasquill-Gifford curves (Turner 1970, 1994) are introduced to calculate  $\sigma_y$  and  $\sigma_z$  (m) as a function of downwind distance (km) for the rural mode. The  $\sigma_y$  coefficient can be calculated by

$$\sigma_y = 465.11628 \cdot x \cdot \tan(TH) , \quad (13)$$

where

$$TH = 0.017453293 \cdot [c - d \cdot \ln(x)] .$$

Also,  $\sigma_z$  can be computed as

$$\sigma_z = a \cdot x^b . \quad (14)$$

For the above equations, the coefficients  $c$  and  $d$  for  $\sigma_y$  and  $a$  and  $b$  for  $\sigma_z$  are presented in Tables 1 and 2, respectively.

**TABLE 1 Parameters Used to Calculate Pasquill-Gifford  $\sigma_y$**

	$\sigma_y = 465.11628 (x) \tan (TH)^*$	
	$TH = 0.017453293 [c - d \cdot \ln (x)]$	
Pasquill Stability Class	<i>c</i>	<i>d</i>
A	24.1670	2.5334
B	18.3330	1.8096
C	12.5000	1.0857
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

\*  $\sigma_y$  is expressed in meters, and  $x$  is the downwind distance, in kilometers.

Source: EPA (1995).

Finally, numerical calculations were made after all components were incorporated into the model. Integrations were made in succession from the nearest line source to the farthest from the receptor  $R_j$ . If the receptor height ( $z$ ) and the reference height ( $z_d$ ) are the same, combining and rewriting Equations 2 and 3 shows that the concentration at the receptor  $R_j$  resulting from the  $i^{th}$  line source appears in both sides, which can be readily solved by transposing,

$$\text{From the first line source, } \chi_{L1} = q_{L1}^{eff} \cdot RHS_1 = (q_A - \chi_{L1} v_{T1}) \cdot \Delta w \cdot RHS_1$$

$$\text{From the second line source, } \chi_{L2} = q_{L2}^{eff} \cdot RHS_2 = [q_A - (\chi_{L1} v_{T1} + \chi_{L2} v_{T2})] \cdot \Delta w \cdot RHS_2$$

.....

$$\text{From the } i^{th} \text{ line source, } \chi_{Li} = q_{Li}^{eff} \cdot RHS_i = [q_A - (\chi_{L1} v_{T1} + \chi_{L2} v_{T2} \dots + \chi_{Li} v_{Ti})] \cdot \Delta w \cdot RHS_i$$

where

$$v_{Ti} = v_{gi} + v_{wi} \text{ (m/s); and}$$

$$RHS_i = (\text{right hand side of Equation 2}) / q_{Li}^{eff}.$$

**TABLE 2 Parameters Used to Calculate  
Pasquill-Gifford  $\sigma_z^*$**

Pasquill Stability Class	$x$	$\sigma_z = a \cdot x^b$	
		$a$	$b$
A <sup>+</sup>	<0.10	122.800	0.94470
	0.10 - 0.15	158.080	1.05420
	0.16 - 0.20	170.220	1.09320
	0.21 - 0.25	179.520	1.12620
	0.26 - 0.30	217.410	1.26440
	0.31 - 0.40	258.890	1.40940
	0.41 - 0.50	346.750	1.72830
	0.51 - 3.11	453.850	2.11660
	>3.11	†	†
B <sup>+</sup>	<0.20	90.673	0.93198
	0.21 - 0.40	98.483	0.98332
	>0.40	109.300	1.09710
C <sup>+</sup>	All	61.141	0.91465
D	<0.30	34.459	0.86974
	0.31 - 1.00	32.093	0.81066
	1.01 - 3.00	32.093	0.64403
	3.01 - 10.00	33.504	0.60486
	10.01 - 30.00	36.650	0.56589
	>30.00	44.053	0.51179
E	<0.10	24.260	0.83660
	0.10 - 0.30	23.331	0.81956
	0.31 - 1.00	21.628	0.75660
	1.01 - 2.00	21.628	0.63077
	2.01 - 4.00	22.534	0.57154
	4.01 - 10.00	24.703	0.50527
	10.01 - 20.00	26.970	0.46713
	20.01 - 40.00	35.420	0.37615
	>40.00	47.618	0.29592
F	<0.20	15.209	0.81558
	0.21 - 0.70	14.457	0.78407
	0.71 - 1.00	13.953	0.68465
	1.01 - 2.00	13.953	0.63227
	2.01 - 3.00	14.823	0.54503
	3.01 - 7.00	16.187	0.46490
	7.01 - 15.00	17.836	0.41507
	15.01 - 30.00	22.651	0.32681
	30.01 - 60.00	27.074	0.27436
	>60.00	34.219	0.21716

\*  $\sigma_z$  is expressed in meters, and  $x$  is expressed in kilometers.

+ If the calculated value of  $\sigma_z$  exceeds 5,000 m,  $\sigma_z$  is set to 5,000 m.

†  $\sigma_z$  is equal to 5,000 m.

Source: EPA (1995).

The model first divides an area source into 10- and 11-line sources, computes the concentration for each line ( $\chi_{Li}$ ) at the receptor  $R_j$ , and sums the concentrations to arrive at the total concentration ( $\chi_A$ ) resulting from the entire area source. Then, if the relative difference of concentrations between 10- and 11-line sources is within a given tolerance (e.g.,  $10^{-4}$ ), the iterative procedures will be terminated. If not, successive iterations continue with further subdivisions in increments of 10 (e.g., 20/21, 30/31, 40/41) until the prescribed convergence condition is satisfied. For computational economy, the maximum number of line sources is limited to 10,000.

### 3 RESULTS AND DISCUSSION

The area factor can be defined as the ratio of the airborne concentration from a finite area source to that from an infinite area source. The methodology used to estimate the area factors is based on the notion that once released into the ambient air, all particulate matter would eventually be removed from the atmosphere by dry and/or wet deposition. The model first calculates the concentrations at the downwind receptor  $R_j$  by increasing the square area source until concentration values are leveled off, that is, approach the maximum values. Then the area factors for square area sources are estimated by dividing their respective concentrations by the maximum concentrations. Some important factors that affect the airborne concentrations are area size, wind speed, wind direction, particle size, location of the receptor, stability class, rainfall rate, and raindrop size.

To illustrate the effects of these factors, the new model was implemented for four wind speeds (1, 2, 5, and 10 m/s at the measurement height [usually 10 m]) and six particle diameters (1, 2, 5, 10, 15, and 30  $\mu\text{m}$ ). Nine square area sources that have side lengths ranging from 1 to 100,000 m and that are oriented perpendicular to the wind direction are analyzed in this study. It is assumed that particles from a source area are emitted into the atmosphere by on-site activities such as mechanical disturbances or wind erosion. This assumption implies that particles are airborne, irrespective of the mechanism of dust generation, and are subsequently subject to a wind stream. For a finite source area, the average airborne concentration can be estimated by integrating the ground-level airborne concentrations over the entire source area. However, this value depends on the frequencies of occurrence of different wind directions and speeds. For simplicity, it is conservative to take the maximum local airborne concentration, that is, the concentration at the center of the downwind edge (receptor  $R_j$  in Figure 1), as the average concentration. The airborne concentrations presented in the rest of the report are the values predicted for the locations at the center of the downwind edge, unless otherwise stated.

The depletion of emission sources associated with radionuclide decay is neglected in the current study. Also, the effective release height ( $H_e$ ), receptor height ( $z$ ), and reference height ( $z_r$ ) are assumed to be zero, that is, at the surface. Parameter values used to estimate airborne concentrations and area factors were selected for typical sites in the United States, where possible (Table 3). On the basis of annual averages for more than 300 National Weather Service stations in the United States, the neutral conditions (represented by Pasquill Class D) occur almost one-half of the observations, while stable (Classes E and F) and unstable (Classes A, B, and C) conditions occur about one-third and one-sixth of the time, respectively (National Oceanic and Atmospheric Administration [NOAA] 1976). Therefore, in this study, neutral stability (Class D) was assumed.

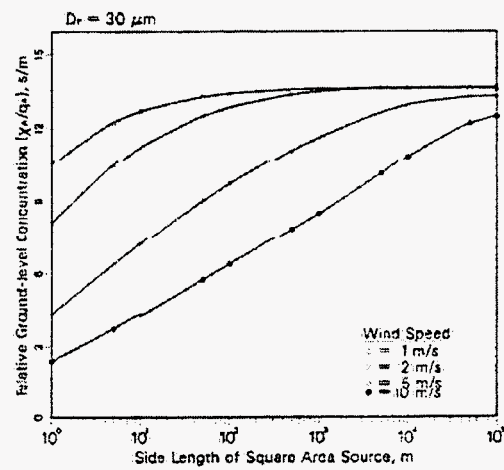
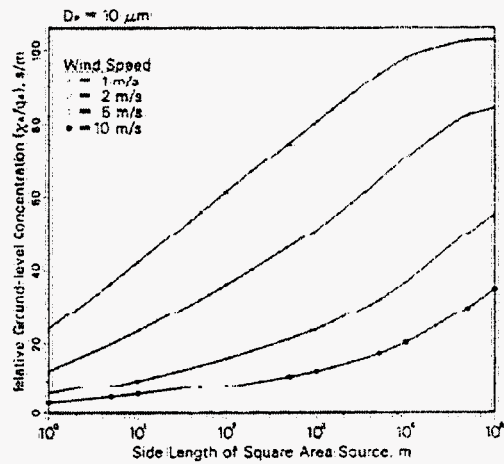
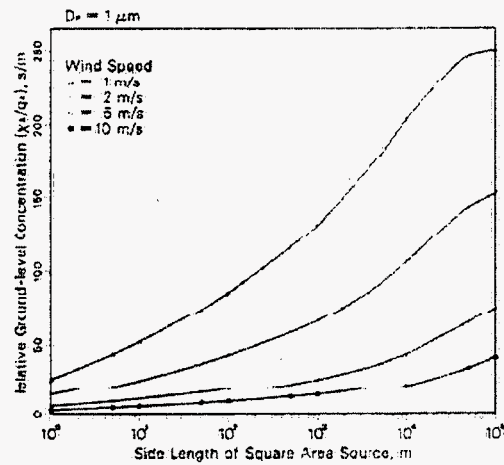
To illustrate the effects of wind speed and particle size on the concentrations at various receptor locations within the site, the relative ground-level concentrations,  $\chi_A/q_A$ , for a  $1,000 \times 1,000$  m area source are shown in Figure 2 for various crosswind and downwind locations

**TABLE 3 Parameter Values Used to Estimate Airborne Concentrations and Area Factors**

Parameter	Values Used	Reference
Rainfall rate	$R = 100 \text{ cm/yr}$	Miller and Thompson (1970)
Particle density	$\rho_p = 2,650 \text{ kg/m}^3$	Brady (1974)
Stability class	D (Neutral)	NOAA (1976)
Diameter of raindrop	$D_r = 10^{-3} \text{ m}$	Miller and Thompson (1970)

(Figure 1). Concentrations at the off-axis receptor (e.g., receptor  $R_2$  in Figure 1) can be estimated by integrating the area source upwind of the receptor with the modification of integration limits in Equation 2. Figure 2 shows relative ground-level concentrations for particle diameters of 1, 10, and 30  $\mu\text{m}$ , respectively, for cases with wind speeds of 2 and 10 m/s. The downwind distances presented in the figure are 100, 500, and 1,000 m (i.e., downwind edge) from the upwind edge of the square source area. As shown in Figure 2, the airborne concentrations increase with the downwind distances and decrease with the crosswind distances from the centerline of the area source parallel to the wind direction. The airborne concentrations along the crosswind distance do not vary significantly except at the locations very close to the crosswind edges of the source area, where the airborne concentrations are predicted to be approximately 50% lower than those at the centerline locations. Also, concentration distributions show symmetry centering around the crosswind edge. (As mentioned in Equation 3, mass fluxes by depositions can be approximated only with concentration at the downwind receptor  $R_j$  without integrating local concentrations along the crosswind distances because of the concentration profile described above.) The airborne concentrations near the crosswind edge are more affected by downwind distance associated with edge effects from the line source. In general, the particle suspension rate driven by wind erosion increases as the wind speed increases. However, the increase in emissions caused by higher wind speed is partially offset by the dilution by the higher wind speed.

To illustrate the effects of the size of the square source area on the airborne concentration, the relative ground-level concentrations  $\chi_A/q_A$  resulting from square area sources of various sizes are shown in Figure 3 for particles 1, 10, and 30  $\mu\text{m}$  in diameter. In general, the  $\chi_A/q_A$  values increase monotonically with the size of the square area source and decrease with wind speed and particle diameter. If the source area is large enough, the airborne concentrations reach a maximum value and do not increase even if the size of the area source is further increased. This means that the airborne concentration thus calculated is similar to that of an area source of infinite size. For smaller particles ( $D_p = 1 \mu\text{m}$ ), the airborne concentrations reach their maximums at side lengths of around 100,000 m or more, being primarily scavenged by precipitation. On the other hand, for particles of 30  $\mu\text{m}$  in diameter and low wind speed, emissions from sources located more than 1,000 m upwind



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**FIGURE 3 Relative Ground-Level Concentrations for  $D_p = 1, 10,$  and  $30 \mu\text{m}$**

do not contribute to concentrations at the downwind receptor location because of high gravitational settling velocity.

To examine the relationship between virtual emissions and depositions within the area source, relative effective source strength and percentage deposited are depicted in Figure 4. The relative effective source strength,  $q_{eff}/q_A$ , is defined as the ratio of the effective source strength at the downwind edge to the source strength at the upwind edge of the square area. The percentage deposited is defined as the total mass deposited by dry and wet deposition up to the downwind edge divided by the total emissions within the site. Note that  $q_{eff}/q_A = 0$  does not necessarily mean 100% deposition of particulates emitted, because airborne particulates still exist over the site. As shown in Figure 4, the wet deposition process is dominant over dry deposition for smaller particles ( $D_p = 1 \mu\text{m}$ ). For particles of  $10 \mu\text{m}$  or larger in diameter, gravitational settling is the major removal pathway. The side length of the square area source where emission from the upwind edge is almost depleted when the plume passes over the downwind edge is more than 100,000 m for a particle diameter of  $1 \mu\text{m}$  and wind speed of 1 m/s. On the other hand, the side length size is approximately 1,000 m for the case of a particle diameter of  $30 \mu\text{m}$  and wind speed of 1 m/s. More particles are deposited at lower wind speeds than at higher wind speeds because at lower wind speeds there are more chances for particles to be removed by dry or wet depositions before they pass over the downwind edge. It is interesting to note that for particles  $1 \mu\text{m}$  in diameter, deposition can be ignored for area sources with side lengths of 1,000 m or less.

The area factors for cases with various wind speeds and particle diameters are shown in Figure 5. General trends for area factors are similar to those for relative ground-level concentrations expressed as  $\chi_A/q_A$  (Figure 3). A physical interpretation for the small area factors is that dilution by the uncontaminated dust blown in from off-site is significant for the case of small particles and high wind speeds. On the other hand, for cases with large particles and low wind speeds, deposition becomes significant, and a maximum airborne concentration can be reached if the source area is sufficiently large. Accordingly, the larger the area factor, the more emitted particulates are removed before reaching the downwind edge.

The old area factors used in the RESRAD code are also plotted in Figure 5. The area factor is approximated by  $A^{1/2}/(A^{1/2} + DL)$ , where  $A$  is the area of contaminated site ( $\text{m}^2$ ) and  $DL$  is the dilution length (m). Although  $DL$  depends on the wind speed, mixing height, resuspension rate, and thickness of the resuspendable dust layer (Appendix A in Gilbert et al. 1983), the geometric mean of the estimates of lower and upper bounds of  $DL$  is used as a default value. In the RESRAD code, the geometric mean (3 m) of 0.03 and 250 m (which correspond to the surface roughness and the height of the stable atmospheric layer, respectively) is assumed to be the default dilution length in predicting the airborne concentration from a finite source area. As shown in Figure 5, the old area factors used in the RESRAD code are larger than those obtained in the new model, except for the case of large particles ( $D_p = 30 \mu\text{m}$ ) and low wind speed. Results show that the dilution length of

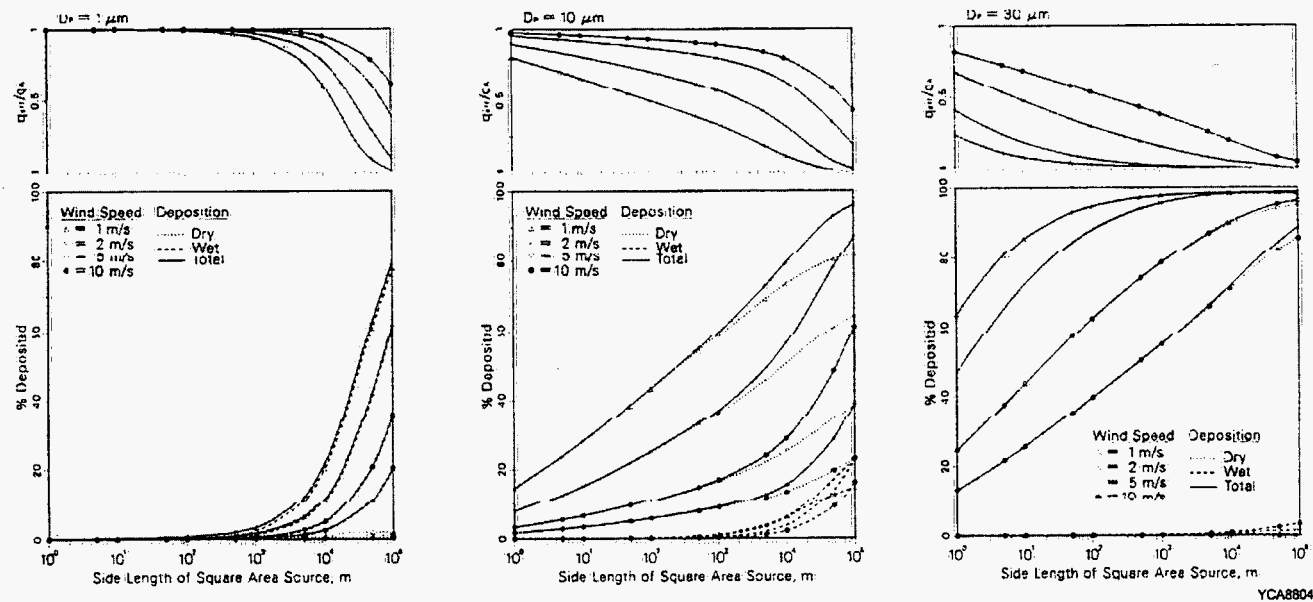
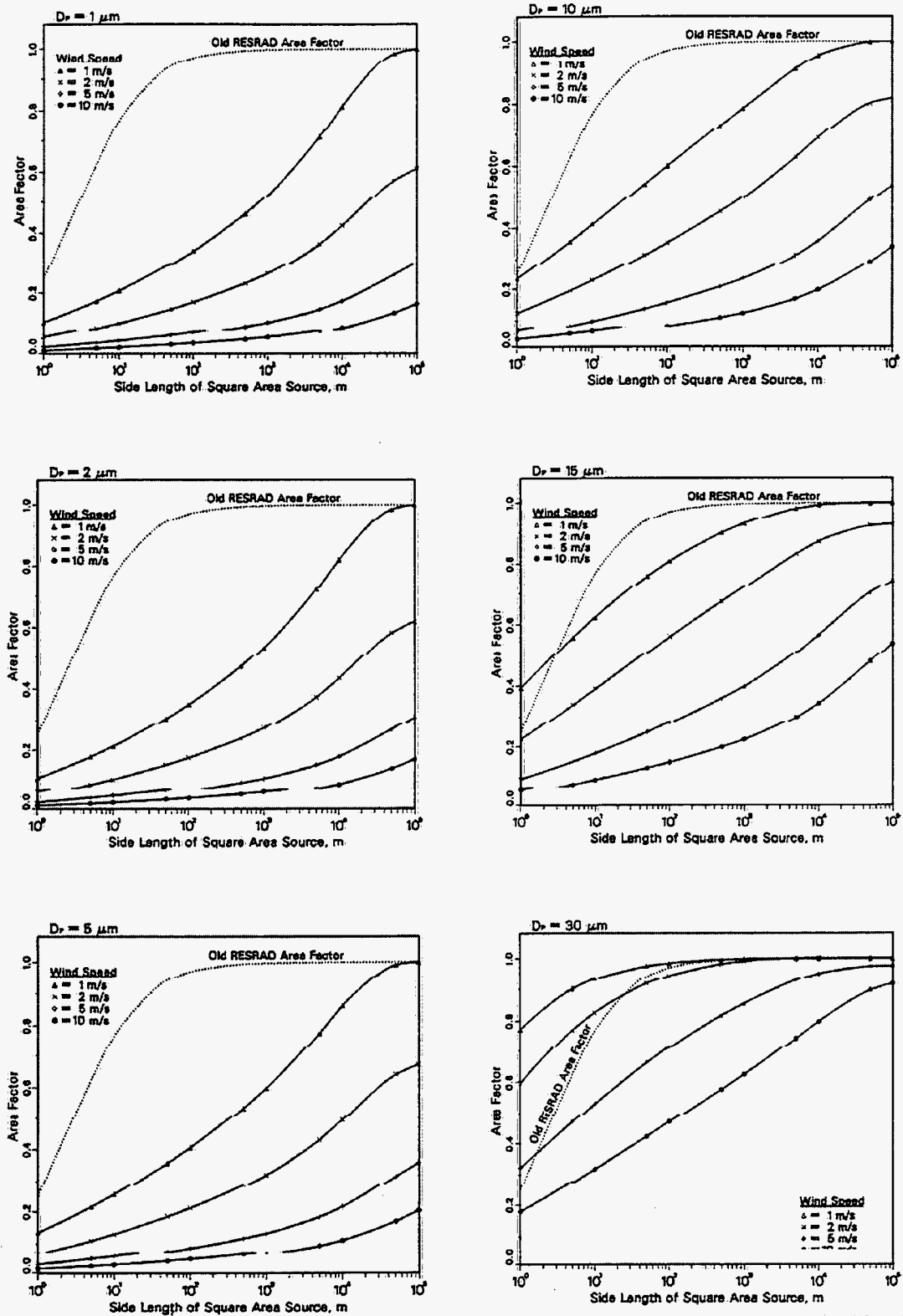


FIGURE 4 Relative Effective Source Strength and Percent Deposited over the Area Source for  $D_p = 1, 10$ , and  $30 \mu\text{m}$



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FIGURE 5 Area Factors for  $D_p = 1, 2, 5, 10, 15$ , and  $30 \mu\text{m}$

3 m as assumed in the RESRAD code provides a reasonably conservative estimate of the airborne concentrations for respirable particle sizes of 1-10  $\mu\text{m}$ .

For direct use in the RESRAD code application, functional expressions are needed to compute the new area factor associated with a finite area source. The desired feature of the functional expression is a sigmoidal behavior with characteristics approaching 0 and 1 of area factors as the side length of source area varies from 0 m to  $\infty$ . Two candidates represented by the logistic growth rate function (Snedecor and Cochran 1980) and the hyperbolic tangent function were tested by regression. The former function was selected because it provides a remarkably good fit to the cases under study and a much better fit than the latter. The equation used to fit the new area factors can be written as

$$\text{Area Factor} = \frac{a}{1 + b (\sqrt{A})^c} \quad (15)$$

where A = area of the contaminated zone. The coefficients a, b, and c for regression curves for the new area factors and related correlation coefficients are presented in Table 4. The regression curve fits very well for the side length ( $\sqrt{A}$ ) of the square area source ranging from 1 to 10,000 m because more weights are assigned to points within that range.

**TABLE 4 Coefficients Derived for the Least Square Regression Curves for Area Factors\***

Particle Diameter ( $\mu\text{m}$ )	Wind Speed (m/s)	Area Factor <sup>+</sup> = $\frac{a}{1 + b(\sqrt{A})^c}$			Correlation Coefficient
		<i>a</i>	<i>b</i>	<i>c</i>	
1	1	1.9005	14.1136	-0.2445	0.9978
	2	1.6819	25.5076	-0.2278	0.9991
	5	0.7837	31.5283	-0.2358	0.9946
	10	0.1846	14.6689	-0.2627	0.9732
2	1	1.8383	13.2106	-0.2451	0.9979
	2	1.6643	24.3606	-0.2273	0.9992
	5	0.8301	32.1641	-0.2339	0.9949
	10	0.1992	15.2539	-0.2598	0.9750
5	1	1.5112	8.7288	-0.2528	0.9982
	2	1.4913	17.2749	-0.2264	0.9992
	5	1.1050	33.8232	-0.2266	0.9966
	10	0.3174	19.9297	-0.2500	0.9838
10	1	1.1445	3.4160	-0.2891	0.9987
	2	1.1396	6.9377	-0.2451	0.9993
	5	1.6353	25.4614	-0.2112	0.9990
	10	1.2075	39.4658	-0.2212	0.9955
15	1	1.0273	1.6289	-0.3945	0.9996
	2	1.0469	3.1582	-0.2813	0.9993
	5	1.5252	11.8208	-0.2085	0.9995
	10	2.5496	40.9663	-0.2012	0.9988
30	1	1.0000	0.2656	-0.5937	0.9998
	2	1.0059	0.7305	-0.5352	0.9995
	5	1.0781	2.0215	-0.2979	0.9980
	10	1.1325	4.4736	-0.2483	0.9996

\* The regression curve fits well for the side length ( $\sqrt{A}$ ) of the square area source ranging from 1 to 10,000 m.

<sup>+</sup> Where  $\sqrt{A}$  is the length of the side of the square area source, in meters.

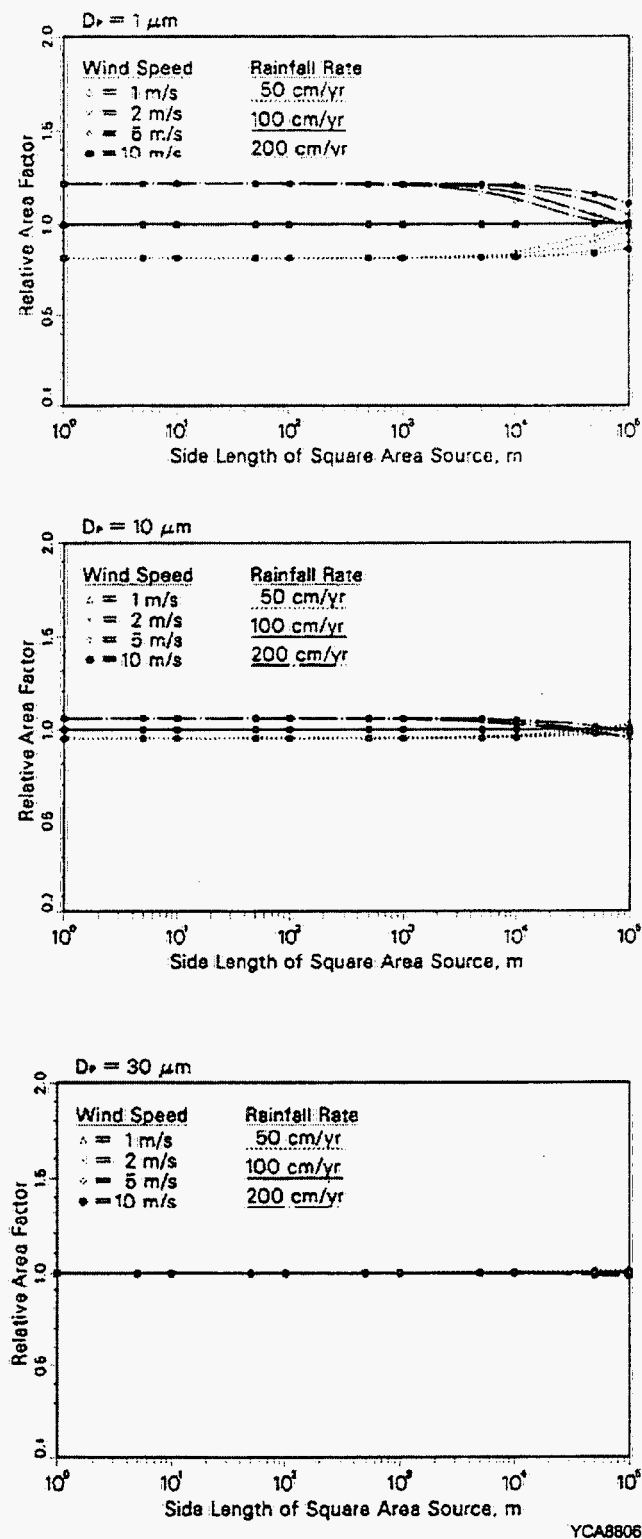
#### 4 SENSITIVITY ANALYSIS

To perform sensitivity analyses for assumed parameters, four cases were simulated as follows (the Base Case is the original simulation):

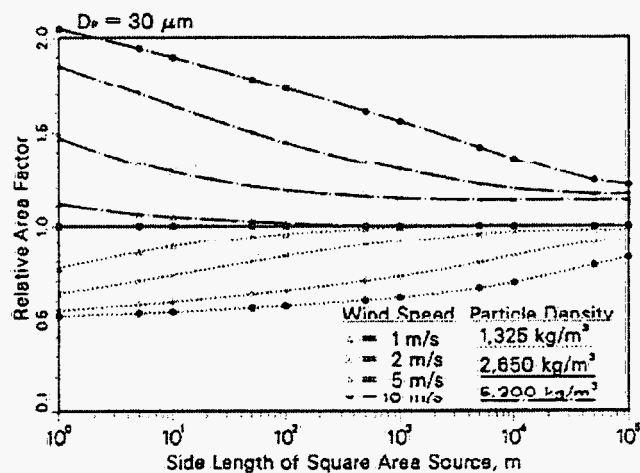
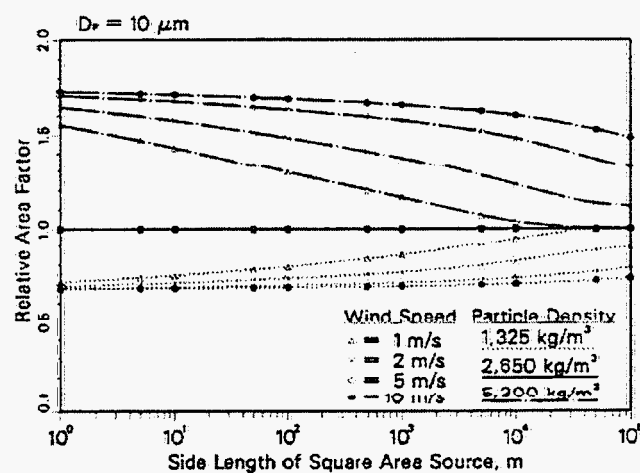
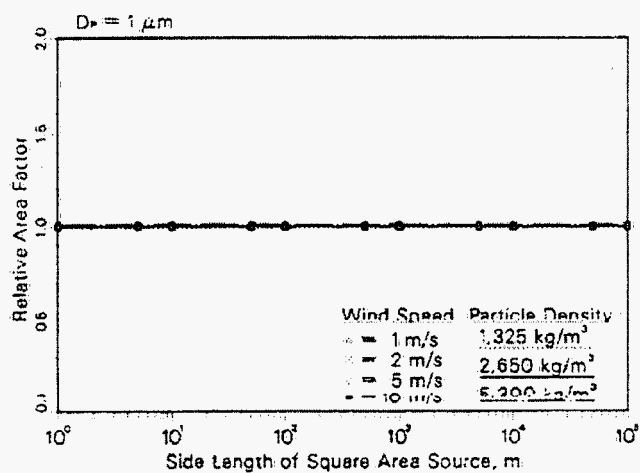
- Case 1: Annual rainfall rate ( $R$ ),
- Case 2: Diameter of a raindrop ( $D_r$ ),
- Case 3: Particle density ( $D_p$ ), and
- Case 4: Atmospheric stability class.

For Cases 1 to 3, 100% perturbation upward and downward for assumed parameter values was tested. For Case 4, the most unstable (Class A) and most stable (Class F) classes were tested. In fact, assuming 100% increase in annual rainfall rate for Case 1 provides identical results to 100% decrease in diameter of a raindrop for Case 2, or vice versa. This situation can be seen in Equation 10, where the annual rainfall rate ( $R$ ) is inversely related to the raindrop diameter ( $D_r$ ).

Relative area factors, which represent the ratio of area factor resulting from parameter perturbations to that for the Base Case, are presented in Figures 6 to 8 for perturbations in rainfall rate, particle density, and atmospheric stability class, respectively. Relative area factors are predicted to be relatively insensitive to changes in annual rainfall rate and, as shown in Figure 6, vary approximately 20, 5, and 0% for 1, 10, and 30  $\mu\text{m}$ , respectively. This result suggests that for smaller particles, wet deposition plays an important role in removal, while for larger particles, gravitational settling is the major removal process. Perturbation of particle density for Case 3 is more sensitive than that of annual rainfall rate for Case 1. As shown in Figure 7, the sensitivity increases with particle size. Although considerable range in particle density may be observed, the values for most mineral soils usually vary between the narrow limits of 2,600 and 2,750  $\text{kg/m}^3$  (Brady 1974). Some mineral topsoils high in organic matter may drop to 2,400  $\text{kg/m}^3$  or lower. Nevertheless, for general calculations, the average arable surface soil may be considered to have a particle density of about 2,650  $\text{kg/m}^3$ . For Case 4, the area factors are most sensitive, especially for smaller particles (Figure 8). This result means that smaller particles are more affected by atmospheric turbulence than larger particles. However, the most unstable (Class A) and most stable (Class F) cases are characterized by conditions under strong solar insolation and under clear nights, respectively, and for both cases, under weak wind. In general, these conditions prevail several hours per day at most, so the sum of the neutral and near-neutral conditions (Classes C, D, and E) is much greater than the sum of extreme conditions (Classes A and F). Therefore, over the long term (e.g., annual average concentrations), the use of neutral stability (Class D) in this study is reasonable because the area factor averaged over site-specific distributions of stability classes is believed to be close to the one calculated only from the neutral stability.

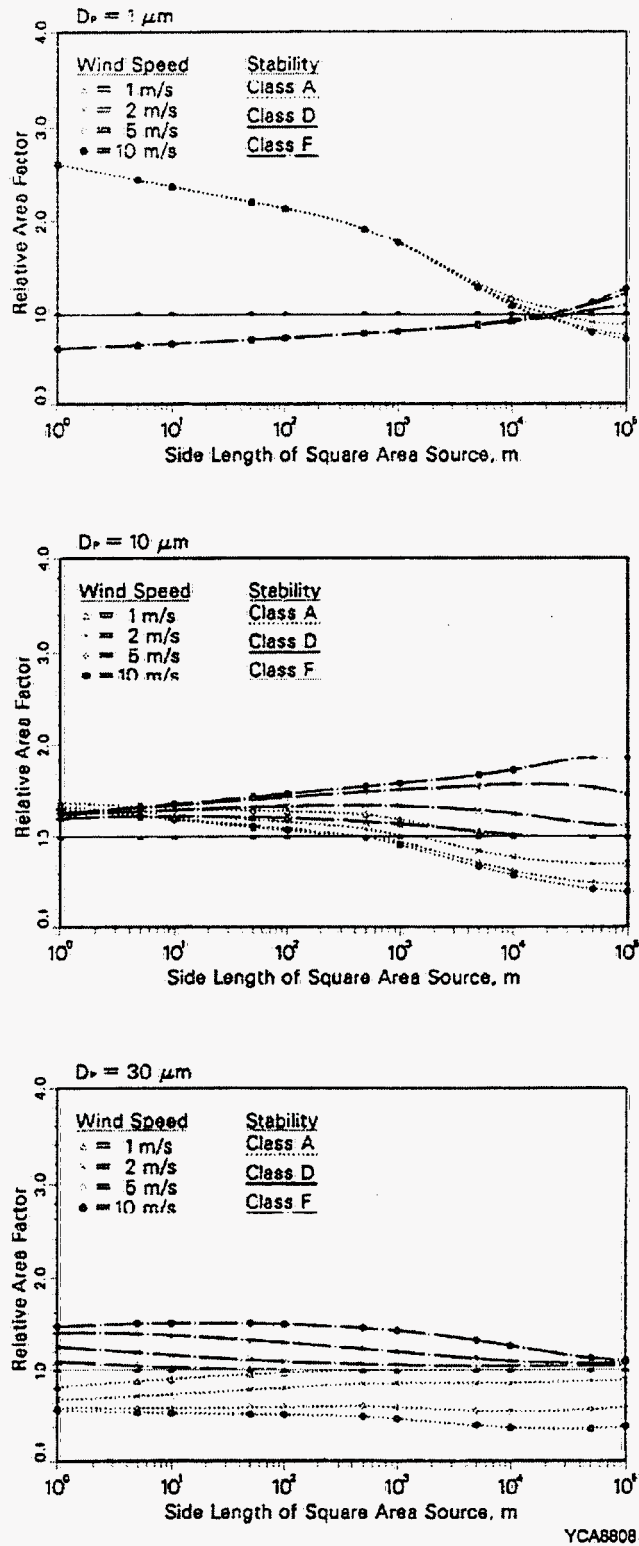


**FIGURE 6** Relative Area Factors Associated with Perturbation of Rainfall Rate for  $D_p = 1, 10$ , and  $30 \mu\text{m}$



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**FIGURE 7 Relative Area Factors Associated with Perturbation of Particle Density for  $D_p = 1$ , 10, and 30  $\mu\text{m}$**



**FIGURE 8** Relative Area Factors Associated with Perturbation of Stability Class for  $D_p = 1, 10, \text{ and } 30 \mu\text{m}$

## 5 SUMMARY AND DISCUSSION

The model described in this report was developed to improve the area factor used in older versions of the RESRAD code (Version 5.70 and older). The new model first approximates the on-site airborne concentrations of particulates emitted from an area source and subsequently calculates area factors as a function of particle diameter, wind speed, and side length of square area source. The assumptions made in developing the model include monodisperse particle size distributions, fixed particle density, fixed raindrop diameter, fixed annual rainfall rate, fixed atmospheric stability, and a neglect of the effect associated with radionuclide decay. Sensitivity analyses for the assumed fixed parameters indicate that the model provides reasonable results. Regression curves were developed for calculating area factors on the basis of the new model (Equation 15), which has been incorporated into RESRAD code version 5.75 and newer.

The new area factor is a function of particle size and wind speed. Because the inhalation dose conversion factors are for particles with an activity median aerodynamic diameter (AMAD) of 1  $\mu\text{m}$ , the particle size is set to 1  $\mu\text{m}$  in the current version of RESRAD. However, the area factor routine is written with the flexibility to use actual particle size data if available in later versions of the RESRAD code. Wind speed is an input parameter of RESRAD. The code will use interpolation based on Equation 15 to calculate the area factor for the user input wind speed and the size of the contaminated zone.

The RESRAD code uses a mass loading factor and an area factor to estimate contaminant concentration in the air suspended from finite area soil sources. The default mass loading factor used in RESRAD 5.70 and older is  $0.0002 \text{ g/m}^3$ . This mass loading factor takes into account short periods of high mass loading and sustained periods of normal farmyard activities for which the dust level may be somewhat higher than ambient. Anspaugh et al. (1974) and Healy and Rodgers (1979) used  $0.0001 \text{ g/m}^3$  for predictive purposes and found that the predicted results and the real cases were comparable. The EPA (1977) has used  $0.0001 \text{ g/m}^3$  for screening calculations. Average ambient concentrations of transportable particles range from  $3.3 \times 10^{-5}$  to  $2.54 \times 10^{-4} \text{ g/m}^3$  in urban locations and from  $9 \times 10^{-6}$  to  $7.9 \times 10^{-5} \text{ g/m}^3$  in nonurban locations. The mass loading value will fluctuate above its ambient level depending on human activities such as plowing and cultivating dry soil or driving on an unpaved road. A default value of  $0.0002 \text{ g/m}^3$  seems to be overly conservative (perhaps by a factor of about 2 to 10). To reduce the over-conservatism in the RESRAD code, the default mass loading factor has been changed from  $0.0002 \text{ g/m}^3$  to  $0.0001 \text{ g/m}^3$  for more realistic (yet for most conditions still conservative) prediction of dust loading.

The new default mass loading factor and the area factor allow RESRAD to predict realistically conservative contaminant concentrations in the air. Hence, the inhalation doses estimated are more realistic. However, if measurement data are available, the measured air contaminant concentrations data should be used in RESRAD analysis.

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## **RFCA Stakeholder Focus Group Attachment D**

**Title:** Evaluation of the Area Factor Used in the  
RESRAD Code for the Estimation of Airborne  
Contaminant Concentrations of Finite Area  
Sources

**Date:** January 11, 2001

**Author:** Argonne National Laboratory

**Phone Number:** 630 252-3107

ADMIN RECORD



## **RFCA Stakeholder Focus Group Attachment E**

Title: Section 4.2 of the Task 2 RAC report, describing  
the change in the air model between the 5.61 and  
5.82

Date: January 11, 2001

Author: Risk Assessment Corporation

Email <http://www.rfcab.org/SALOPreports.html>

ADMIN RECORD

# **FINAL REPORT**

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## **Task 2: Computer Models**

### **Radionuclide Soil Action Level Oversight Panel**

**July 1999**

*Submitted to the Radionuclide Soil Action Level Oversight Panel  
in Partial Fulfillment of Contract between RAC and the Rocky Flats Citizen's Advisory Board*



# FINAL REPORT

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## Task 2: Computer Models

Radionuclide Soil Action Level Oversight Panel

July 1999

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## CONTENTS

Abstract .....	1
1. INTRODUCTION.....	3
2. SOIL ACTION LEVELS.....	7
2.1. Formulation.....	9
2.2. Stochastic SALs.....	12
2.3. Exposure scenarios.....	13
3. SITE CONCEPTUAL MODEL.....	19
3.1. Transport pathways.....	20
3.1.1. Availability of residual radioactivity in surface soil over time.....	20
3.1.2. Spatial disaggregation of soil.....	21
3.1.3. Resuspended contaminated soil.....	22
3.1.4. Groundwater and surface water transport.....	25
3.1.4.1. Overview of RFETS surface and groundwater hydrology.....	25
3.1.4.2. Implications of ground and surface water pathways.....	26
3.2. Exposure Modes.....	28
4. CANDIDATE COMPUTER PROGRAMS.....	31
4.1. Introduction.....	31
4.1.1. Verification of Computer Programs.....	32
4.1.2. Validation of Computer Programs.....	33
4.2. RESRAD.....	35
4.2.1. RESRAD overview.....	35
4.2.2. Code acquisition.....	38
4.2.3. Changes in the area factor for resuspension.....	40
4.3. MEPAS.....	43
4.4. GENII.....	44
4.4.1. Code overview.....	44
4.4.2. Code features relevant to calculating soil action levels for Rocky Flats...	45
4.4.3. Code acquisition and testing.....	47
4.5. MMSOILS.....	49
4.6. DandD.....	50
4.6.1. Code overview.....	50
4.6.2. Code features relevant to calculating soil action levels for Rocky Flats...	51
4.6.3. Code acquisition and testing.....	52
5. CONCLUSIONS AND RECOMMENDATIONS.....	55
6. REFERENCES.....	57

## FIGURES

2.1-1. Geometric interpretation of the sum of ratios (SR) for two radionuclides ( $N = 2$ ) and one scenario ( $S = 1$ ).....	10
2.2-1. Schematic illustration of uncertainty distributions for the sum of ratios of soil concentrations divided by the corresponding soil action levels.....	13
3.1.2-1. Plutonium-239 concentrations in soil ( $\text{Bq kg}^{-1}$ ) at RFETS along a $90^\circ$ transect (eastward) from the 903 pad area.....	22
4.2.3-1. Comparison of the old and new RESRAD area factors for particle size $1\ \mu\text{m}$ , plotted against the side length of a square contaminated area.....	42

**TABLES**

2.3-1. Key Parameter Summary for the Rocky Flats Environmental Technology Site Radionuclide Soil Action Levels Scenarios.....	17
3.1.5-1. Soil Action Levels for the Residential Exposure Scenario at the 85 mrem Level Including and Excluding the Groundwater Pathway.....	27
4.4.3-1. Key Input Parameters for the Proposed SAL Conceptual Site Model.....	48
4.4.3-2. Dose-to-Soil Ratios ( <i>DSR</i> , mrem (pCi g <sup>-1</sup> ) <sup>-1</sup> ) for RESRAD V. 5.61 and GENII.....	49
4.4.3-3. Percent Difference Between the DSRs for RESRAD V. 5.61 and GENII.....	49
4.6.3-1. Key Input Parameters for the RESRAD to DandD Comparison.....	52
4.6.3-2. Dose-to-Soil Concentration Ratios ( <i>DSR</i> , mrem (pCi g <sup>-1</sup> ) <sup>-1</sup> ) for RESRAD and DandD.....	53
4.6.3-3. Percent Difference Between the DSRs for RESRAD and DandD.....	54

## **REVIEW OF THE RADIONUCLIDE SOIL ACTION LEVELS AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE**

### **TASK 2. COMPUTER MODELS**

#### **Abstract**

This report discusses *Risk Assessment Corporation's* approach to soil action levels (SALs) in context with some computer programs that can be used to calculate them. A mathematical formulation is provided, along with an approach to uncertainty analysis with SALs. Dependence of SALs on exposure scenarios is emphasized. Two sets of scenarios are presented: (1) benchmark scenarios adopted by the Action Levels and Standards Framework for Surface Water, Ground Water and Soils (ALF) Working Group, consisting of members from the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Colorado Department of Public Health and Environment (CDPHE), and Kaiser-Hill; and (2) some refined versions, which are provided for illustration and discussion. Five candidate computer programs were considered for their usefulness in estimating dose and SALs: RESRAD, MEPAS, GENII, MMSOILS, and DandD. RESRAD and GENII tentatively met the requirements set for future computations, which included not only appropriateness of the models implemented, but also the adaptability of the code to command-line execution from a front-end control program. This mode of operation would facilitate customized Monte Carlo analysis, and scripted preprocessing of input data and post-processing of output.

## 1. INTRODUCTION

This report considers specific computer models and methods that might be useful in the task of setting radionuclide soil action levels (RSALs) for the Rocky Flats Environmental Technology Site (RFETS). The models here reviewed are RESRAD, MEPAS, GENII, MMSOILS, and DandD. They are reviewed for their applicability to this task based on criteria discussed in Section 4. For the purpose of this report, RSALs are defined as radionuclide concentration (activity) levels in a contaminated layer in soil above which remedial action must be taken to prevent people from receiving an annual radiation dose greater than a specified dose limit. The Department of Energy (DOE) has performed calculations of soil action levels with the RESRAD program, which is a DOE product developed specifically for implementing the agency's approach to residual radionuclides in soil (DOE/EPA/CDPHE 1996). A part of the scope of this project is to review these calculations for choice of the parameters that were used in RESRAD, but the review is placed in the larger context of the scientific and technical appropriateness of the models and approach implemented in RESRAD, and whether other programs - or other models and approaches - might be preferred to the one followed by DOE. The parameter choices for RESRAD are a subject of Task 3. The goal of this report is a discussion and comparison of environmental assessment programs that might be used for developing soil action levels for RFETS; as required by the contract, the comparison includes RESRAD.

Before we can discuss the question of suitability of various computer programs for calculating soil action levels, we must make clear our conception of the task to which such programs would be applied. The goal is to protect people who may, in the near or distant future, come into contact with a site where radionuclides contaminate the soil at levels above background. Soil action levels are quantities, one or more per radionuclide, that are computed on the basis of environmental transport models, annual radiation dose limits, and formal assumptions (called exposure scenarios) about the nature and extent of *possible* contact that people *might* have with the site. For a single radionuclide, scenario, and dose limit, the soil action level is that concentration of the radionuclide in the soil that would lead to a maximum predicted annual dose equal to the annual dose limit. For multiple radionuclides, the criterion is more complicated. The concentration of each radionuclide is divided by the respective soil action level, as previously defined. The ratios are summed for all of the radionuclides, and if the sum exceeds 1 for one or more of the exposure scenarios, some action or special attention is indicated. Otherwise (the sum of ratios is less than or equal to 1), the interpretation is that no annual dose limit would be exceeded, and *by that criterion* the radionuclide levels are acceptable. If only one radionuclide is present, the sum of ratios reduces to a single ratio, but the interpretation is the same. Section 2 goes into detail about the definition of soil action levels, the environmental transport models, and the exposure scenarios.

Our immediate point is that for each radionuclide in the soil, we calculate a quantity called a soil action level, which depends on environmental transport models, annual radiation dose limits, and exposure scenarios. As a matter of common practice, each soil action level is calculated deterministically, which is to say that it represents a single number, typically without indications of uncertainty. Similarly, when the ratios of radionuclide levels divided by

soil action levels are summed and compared with 1, the sum of ratios is itself a deterministic quantity, that is, a single number, with typically no indication of uncertainty.

Yet the movement of each radionuclide through environmental media and into possible contact with people is an uncertain process. Although this movement is fundamentally constrained by laws of physics, chemistry, and biology, models are, of necessity, empirical simplifications of reality, and much of the parametric information on which the models depend is not well known. Contemporary modeling practice explicitly recognizes this state of affairs by treating model parameters and state variables as probability (or uncertainty) distributions, and the calculation propagates the joint uncertainty in the parameters through to the endpoints of the calculation, which, in the case at hand, are the soil action levels and sum of ratios.

When uncertainties in soil action levels are considered, the decision is not so straightforward as in the deterministic case, when the sum of ratios is a single number that is to be compared to 1. When the calculation is stochastic (i.e., takes uncertainties into account), the sum of ratios is a distribution, and one must base a decision on *how probable it is* that the sum exceeds 1. If that probability is small, then one may be willing to forgo action, even though there is some acknowledged possibility that some annual dose limit could be exceeded (indeed, that possibility nearly always exists, even though many conventional calculations do not explicitly recognize it). Section 2.2 goes further into this question. We make the point here, however, that the development and interpretation of soil action levels should follow contemporary methods for incorporating uncertainty into environmental transport modeling. Accordingly, we consider the suitability of various computer programs to provide the necessary machinery.

This report summarizes and compares five prominent computer programs that are configured for environmental assessment: RESRAD, MEPAS, GENII, MMSOILS, and DandD. All of these programs have been developed with support from government agencies, and all have versions that install and execute under Microsoft® Windows 95 or NT. RESRAD, as we mentioned above, is intended to be used in connection with analyzing remediation of radionuclide-contaminated soils at DOE facilities. DOE generally grants access to RESRAD to DOE employees and contractors on DOE-funded projects. MEPAS, which was developed at Pacific Northwest Laboratories (PNL) and is now commercially marketed, is a large multimedia environmental transport program of extensive scope, which is applicable to radioactive and nonradioactive pollutants in many environmental media. GENII, also developed at PNL, is a highly modular radiological assessment system, which provides internal and external dose estimates for exposure through all pathways that are ordinarily considered in environmental radiological assessments. GENII has been under development for more than a decade and is unlikely to be modified further by its developers. MMSOILS, which was developed for the Environmental Protection Agency, is a large multimedia environmental transport program that was designed for screening assessments of chemical contamination. Although it does not treat radioactivity and decay chains, it was included in this review because it could possibly be useful for radionuclides in soils by using stable chemicals as surrogates for radionuclides and performing auxiliary decay-chain calculations external to the program. MMSOILS executables and source code are freely available from an EPA web server. DandD is currently under development by Sandia National Laboratory for the U.S. Nuclear Regulatory Commission (NRC).

We compare these programs with respect to features that are relevant to their possible use in computing soil action levels for the RFETS (Section 4). We draw on documentation distributed with the programs and on published comparisons by authors who participated in the development of the programs (Laniak et al. 1997; Mills et al. 1997). Comparisons of soil action levels developed with some of the programs is the subject of Task 5.

We hesitate to anticipate parameter uncertainties that may be dominant in methodologies for soil action levels until calculations have been done with site-specific data. However, we consider the level of uncertainty associated with the resuspension mechanism to be of sufficient concern that it should be raised in this report. This mechanism drives the inhalation exposure pathway and contributes to other pathways (such as deposition on garden vegetables and pasture grass) that could be considered in some scenarios. Models affecting this pathway were changed in RESRAD Version 5.75, although the calculations reported in the soil action levels document (DOE/EPA/CDPHE 1996) were performed with an earlier version of the program. We compare the previous and current versions of the models for this pathway in Section 4.2.3. Predictions of resuspension by the current version tend to be substantially lower than those of pre-5.75 versions.



## 2. SOIL ACTION LEVELS

Soil action levels may be defined for sites where radionuclides remain in soil at levels that detectably exceed background. Their purpose is to express a possibly complex set of criteria for action that would be taken to protect people who might be exposed to the radioactivity in the near or distant future. Once a set of soil action levels is calculated for the radionuclides of concern, that set may be combined in a sum of ratios with measured or hypothesized concentrations of the radionuclides in soil (each ratio is a soil concentration divided by the corresponding action level) to determine whether the criteria do (or would) call for action, given the measured or hypothesized levels. The soil action levels as defined do not depend explicitly on the actual radionuclide concentrations, because they are determined by using the transport models to calculate levels in soil that would give the limiting annual doses. Thus the same set of soil action levels might be used for determining the need for remediation (based on existing concentrations), planning the remediation (hypothesizing reductions that would result from proposed actions), and verifying that the remediation has been successful (using post-remediation survey results).

The soil action levels depend on four things:

- (1) Predicted movement of the radionuclides through environmental media and into potential contact with people (environmental transport models and pathway analysis)
- (2) Possible patterns of contact that hypothetical people are assumed to have with the radionuclides in the near or distant future; also, physiological characteristics that would affect the estimation of radiation dose that these hypothetical people would receive (exposure scenarios)
- (3) Dosimetric models and data, including radionuclide-specific internal dose coefficients and dose rate factors for external exposure to gamma-emitting radionuclides; these models and data are used to estimate radiation dose to any hypothetical individual with known exposure to radionuclides in the environment (radiation dosimetry)
- (4) Annual radiation doses that express protective thresholds for people who might be exposed to the radionuclides (annual dose limits).

The calculation of soil action levels requires environmental transport models (item 1) that consider the various environmental pathways from the source to people who might be exposed (item 2) and methods of radiation dosimetry (item 3) to estimate dose corresponding to the predicted exposure. The purpose is to enable us to see how to control the current levels of the radionuclides in the soil so that the annual radiation dose from these radionuclides to any person who might be exposed to them in ways foreseen in the scenarios (item 2) cannot exceed the annual dose limits (item 4). Section 2.1 presents details of the formulation of the soil action levels.

If the environmental transport models take parameter uncertainties into account, the soil action levels will be represented as a joint probability distribution (the term "joint" indicates possible correlation among the soil action levels), and the sum of ratios (radionuclide concentrations in soil divided by the corresponding soil action levels) is a one-dimensional distribution that must be compared with 1. In this case, we must ask what is the probability that the sum of ratios exceeds 1, and if that probability is acceptably small, one may be willing to accept that exceeding the annual dose limit would be highly unlikely, although possible. Section 2.2 goes into greater detail about uncertainty analysis for soil action levels.

Exposure scenarios are descriptions of characteristics and behaviors of hypothetical individuals who are assumed to have a specified pattern of contact with the radionuclides

originating in the soil at the site. Behaviors would include time regularly spent in one or more locations on or near the site or eating foods from contaminated sources (e.g., a family garden planted in contaminated soil). Characteristics include variables correlated with dose, such as average breathing rates or dietary habits ( $\text{kg day}^{-1}$  of various food types). Soil action levels may depend on one or more exposure scenarios. Section 2.3 includes additional discussion of scenarios and some examples that may be relevant to the RFETS soil action levels.

The reader is reminded that the validity of soil action levels rests on the information and assumptions that go into their calculation. The calculation anticipates the above-background presence (but not the concentrations) of specific radionuclides and considers only dose limits corresponding to those radionuclides, ignoring any others that may be present. The soil action levels depend on specific exposure scenarios, but the formulation of the scenarios may be quite arbitrary. Thus, it is possible to consider scenarios located in such a way that they would minimize dose from the site and to fail to formulate scenarios based on locations or other assumptions that would tend to maximize dose from the site. Even though the soil action levels do not depend on initial concentrations of the radionuclides of concern, it is recommended that all available information on the spatial distributions of initial radionuclide concentrations be considered as the exposure scenarios are formulated. Otherwise the resulting soil action levels may not impose the desired dose limitation. The implicit nature of soil action levels makes it possible for them to conceal models and assumptions that may not be appropriate for a particular site from users who do not have complete information about the derivation of the soil action levels.

The reader should also be aware that it is always possible, in principle, to avoid soil action levels altogether and to base remediation planning and verification on direct simulations with the data, models, and scenario definitions that would have been used to calculate the soil action levels. That is to say, given a set of measured or hypothesized radionuclide concentrations in soil, the environmental transport and dosimetric models are applied directly to these soil data to estimate annual dose over time to the subjects of the exposure scenarios and thus to determine whether or not dose limitations would be exceeded. Soil action levels need not be calculated at all, and this technique has been employed at various facilities analyzed in Task 1, including Maralinga, Australia, and the Nevada Test Site. This approach has the advantage that its explicit nature draws attention to the numerous elements that go into the estimation of dose as a function of initial concentrations of the radionuclides of concern. Reviewing these models, scenarios, and other data can cause the discovery of errors and assumptions that may not be appropriate for the site under consideration. The disadvantage is some added computational effort, although this disadvantage may have relatively less weight when uncertainties are introduced into the simulations. The current availability and speed of modern computers makes the direct calculation practical for virtually any technical group with the requisite knowledge, whereas decades ago, tables of hazard indices and action levels were essential for decision makers with little or no access to computing equipment that would have made direct computation possible. For example, in the 1960s and 1970s, the International Commission on Radiological Protection (ICRP) published tables of limiting air concentrations for radionuclides in occupational environments, based on dose limitation criteria, whereas contemporary ICRP publications emphasize dose coefficients, on the assumption that any reader has the means to use these coefficients to estimate dose from measured or hypothesized air concentrations of radionuclides.

## 2.1 Formulation

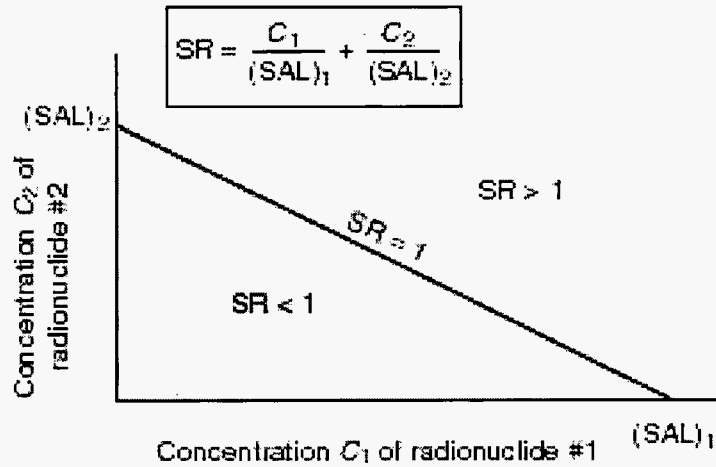
This section is intended primarily for specialists. It gives mathematical details about the formulation of soil action levels and their relationship to the models and scenarios. The general reader may wish to skip ahead to Section 2.2.

As we shall see in Section 3 and its subsections, it could be desirable to subdivide the RFETS into some number  $R$  of subregions, such that the concentration of each radionuclide can be treated as if it were spatially uniform in each subregion. Such a disaggregation would permit an improved representation of so-called hot spots and may offer some advantages in planning and verifying remediation steps. But for the initial discussion of the formulation of soil action levels, we consider a single uniformly contaminated region. At the end of this section, we indicate the more general forms of the formulas when multiple subregions are considered.

It is necessary to define a set of soil action levels for each of the exposure scenarios under study. For any set of radionuclide concentrations  $(C_1, K, C_N)$  and scenarios indexed  $s = 1, K, S$ , we can write a sum of ratios for each scenario  $s$  as

$$(SR)_s = \sum_{i=1}^N \frac{C_i}{(SAL)_{si}}, \quad s = 1, K, S \quad (2.1-1)$$

where details of the computation of the denominators are given below. A simple geometric interpretation for  $N = 2$  and  $S = 1$  is shown in Figure 2.1-1. The  $(SAL)_{si}$  will be calculated in such a way that the probability that  $(SR)_s \leq 1$  is equal to the probability that the dose limit for scenario  $s$  is not exceeded. But we must base our soil criterion on the probability that  $\max_s (SR)_s \leq 1$  (the notation  $\max_s (SR)_s$  means the largest of the sums of ratios), so that we control all scenarios by controlling the ones for which potential exposure is maximum. In general, we allow both the numerators and the denominators in the sum in Equation 2.1-1 to be uncertain quantities. The soil concentrations will come from a joint distribution based either on sampling or existing data. The denominators are based on applicable pathway calculations of dose for the respective scenarios, using Monte Carlo methods to estimate joint distributions. The term "joint" indicates the possibility that there may be correlations among the soil concentrations for different radionuclides, and the denominators may be correlated among scenarios that depend on common pathways (although as a practical matter, we may wish to treat different scenarios as if they were independent). The numerators and denominators will generally be independent.



**Figure 2.1-1.** Geometric interpretation of the sum of ratios (SR) for two radionuclides ( $N = 2$ ) and one scenario ( $S = 1$ ). All points  $(C_1, C_2)$  on the line represent pairs of concentrations for which the sum of ratios equals 1. For all points in the shaded rectangle beneath the line, the pair of concentrations corresponds to a sum of ratios less than 1 and thus to annual doses that do not exceed the annual dose limit. The concentration pair for any point above the line would lead to an annual dose that exceeds the annual dose limit.

Let us define the transfer function  $T_{smi}$  as the quantity that converts a concentration  $C_i$  of radionuclide  $i$  in the soil to the dose estimate  $D_{smi}$ . The subscript  $s$  stands for the scenario, and  $m$  denotes the particular pathway. The transfer function is something that would be computed by an appropriate environmental transport model. The dose relation for a single radionuclide, scenario, and pathway is

$$D_{smi} = T_{smi} ? C_i . \quad (2.1-2)$$

Each scenario has a dose limit, and the dose limits are not necessarily the same for all scenarios. Let us denote the limit for scenario  $s$  by  $\Delta_s$ . Then the requirement for the scenario is that

$$\sum_{i=1}^N \sum_{m=1}^M C_i T_{smi} = \sum_{i=1}^N \sum_{m=1}^M C_i T_{smi} \leq \Delta_s \quad \text{for each } s = 1, K, S . \quad (2.1-3)$$

If we divide Eq. 2.1-3 by the dose limit  $\Delta_s$  and rearrange the second summation, the condition can be expressed as

$$\sum_{i=1}^N \frac{C_i}{\Delta_s / \sum_{m=1}^M T_{smi}} \leq 1, \quad s = 1, K, S , \quad (2.1-4)$$

and this shows us how to define the SALs for the scenarios:

$$(\text{SAL})_{si} = \frac{\Delta_s}{\sum_{m=1}^M T_{smi}}, \quad s = 1, K, S, \quad i = 1, K, N . \quad (2.1-5)$$

Putting this expression into Equation 2.1-1 defines the scenario-dependent sum of ratios  $(\text{SR})_s$ . The condition

$$(SR)_s \leq 1, \quad s=1, K, S \quad (2.1-6)$$

is equivalent to the dose-limitation condition of Eq. 3, in the sense that (2.1-3) holds for each  $s=1, K, S$  if and only if (2.1-6) holds for each  $s=1, K, S$ . Thus, to achieve the required dose limitation, we must require that Equation 2.1-6 hold for all  $s$ , or equivalently

$$\max_s (SR)_s \leq 1. \quad (2.1-7)$$

Of course this requires us to define a separate sum of ratios for each scenario. There is a way to avoid this. We may write

$$(SR)_s = \frac{N}{i=1} \frac{C_i}{(SAL)_{si}} \leq \frac{N}{i=1} \frac{C_i}{\min_s (SAL)_{si}} = (SR), \quad (2.1-8)$$

where the last equality in Eq. 8 defines a scenario-independent sum of ratios (SR). Now if we impose the condition

$$(SR) \leq 1, \quad (2.1-9)$$

Equation 2.1-9 implies that the inequality of Equation 2.1-7 follows, so that the dose limitation is met for all scenarios. But it does not work the other way, which is to say the following: there may be some sets of soil concentrations for which (2.1-7) would be satisfied but which would violate (2.1-9). Thus (2.1-9) (as defined by (2.1-8)) is a more stringent condition, which could impose lower soil concentrations. Using Equations 2.1-8 and 2.1-9 as the criterion also introduces a complication when we introduce probability and uncertainty.

We regard the  $C_i$  and the  $(SAL)_{si}$  as uncertain quantities, and consequently we must interpret inequalities like (2.1-3) and (2.1-6) probabilistically. The probability that these equivalent inequalities hold is the probability — based on the uncertainty of the radionuclide concentrations and the environmental transport calculation — that the dose limitation for all scenarios will be collectively met. To estimate this probability, we sample from the joint distribution of the soil concentrations, and from the distributions of the scenario-dependent soil action levels (Equation 2.1-5); using Monte Carlo methods, this permits us to count the number of times during the run the inequality (2.1-4) holds for all scenarios  $s$ . Dividing this number by the total number of Monte Carlo cycles gives our estimate of the probability.

If we use criterion (2.1-9) instead, we can estimate the probability that the inequality (2.1-9) holds, but that probability is not the same as the probability that (2.1-7) holds (as we previously pointed out, inequalities (2.1-9) and (2.1-7) are not equivalent: (2.1-9) implies (2.1-7), but not the other way around). The probability of (2.1-7) will in general be larger than the probability of (2.1-9). This approach imposes a more stringent requirement and could require additional remediation to meet the criterion, given the scenarios, the dose limit numbers, and a specified probability that Equation 2.1-9 holds.

As we mentioned at the beginning of this subsection, it could be useful to consider a subdivision of the RFETS into some number  $R$  of subregions and to treat soil concentrations of radionuclides as being spatially uniform within any given region (we would hope to avoid this level of complexity). We conclude this section with the more general forms of the equations that define the soil action levels in such a multiple-source environment. We use the indexing variable  $r=1, K, R$  for the subregions ( $R=1$  corresponds to the previous case). For  $R>1$ , we have a larger number of soil action levels: whereas in the previous formulation, there were  $NS$  (one for each radionuclide and scenario), now the number is  $NSR$  (one for each radionuclide, scenario, and source subregion). We add another index to the concentration  $C_i^{(r)}$ , and to the transfer function  $T_{smi}^{(r)}$ , and we define the soil action level as

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$$(\text{SAL})_{si}^{(r)} = \frac{\Delta_s}{M \sum_{m=1}^M T_{smi}^{(r)}}, \quad i=1, K, N, s=1, K, S, r=1, K, R \quad (2.1-10)$$

and the sum of ratios for scenario  $s$  as

$$(\text{SR})_s = \sum_{r=1}^R \sum_{i=1}^N \frac{C_i^{(r)}}{(\text{SAL})_{si}^{(r)}}, \quad s=1, K, S. \quad (2.1-11)$$

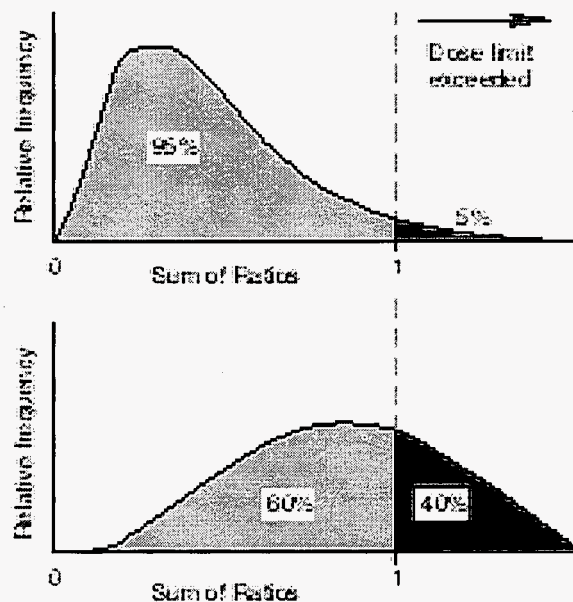
Using this form of  $(\text{SR})_s$ , we still apply Equation 2.1-7 as our criterion for dose limitation.

It is important to remember that the compact formulations shown in this subsection conceal a great deal of specific detail about the scenarios and environmental models. We describe a possible set of scenarios in Section 2.3. Sections 3, 3.1, and 3.2 outline a conceptual approach to environmental modeling for the site and the modes of exposure that would be relevant for the site and the scenarios.

## 2.2 Stochastic SALs

Uncertainty analysis is now regularly applied to environmental modeling. Parametric uncertainty is concerned with the propagation of uncertainty in parameter values through the simulations to the resulting estimates of concentrations in exposure media or to dose or risk. The usual tools are Monte Carlo techniques. In their simplest form, these techniques consist of assigning a probability distribution to each parameter that is treated as uncertain. The simulation is performed a large number of times (usually 1000 if practical), and at the beginning of each repetition, a number is sampled from the distribution associated with each parameter. This random set of parameter values is used to parameterize the model, and the corresponding result (say a dose) is calculated. The 1000 doses define an empirical distribution for the dose quantity. This distribution is considered an estimate of the quantity and represents the propagated uncertainty. Sometimes additional elaboration is necessary, such as the simulation of correlated subsets of the parameters. But the end product is an uncertainty distribution for each calculated quantity.

When the quantities to be calculated are soil action levels, there is no special difficulty in applying uncertainty analysis. The procedure produces an uncertainty distribution for each SAL. Each of these distributions is a marginal distribution of a multivariate joint distribution of the possibly correlated SALs. These correlations need to be preserved for the next step, which is combining the SALs with measured or assumed soil concentrations of the respective radionuclides by forming ratios: soil concentration divided by SAL. The ratios are summed as in the deterministic case, but in the stochastic case there are, say, 1000 sums of ratios, which define an empirical uncertainty distribution of the sum of ratios (SR) quantity. It is this distribution that is compared with 1 to determine the probability that 1 will be exceeded. If, for example, the value 1 occurs at the 95th percentile of the distribution, then the probability that the sum of ratios will exceed 1 is 5%, or one chance in 20. This might be accepted as a small probability of exceeding the dose standard imposed on the scenario from which the SALs were derived. This probability is associated with uncertainties in environmental data and models; it does not come from the scenario itself, which is considered fixed (Section 2.3). If the value 1 occurred at the 60th percentile of the sum of ratios distribution, the probability of exceeding the dose limit would be 40%, which anyone would likely consider large. In that case, some action or attention would be called for. Figure 2.2-1 is a schematic showing two sum of ratios uncertainty distributions corresponding to the two examples we have just given.



**Figure 2.2-1.** Schematic illustration of uncertainty distributions for the sum of ratios of soil concentrations divided by the corresponding soil action levels. In the top panel, the probability is 5% that the dose limit for a scenario would be exceeded. In the bottom, the probability is 40%.

### 2.3 Exposure scenarios

Exposure scenarios describe the characteristics and behaviors of hypothetical individuals who might have some contact with the radionuclides in the soil at the site. The people described by the scenarios live, work, or use the Rocky Flats site for recreational purposes. For the soil action level assessment, a succession of hypothetical individuals over time (for example, 1000 years) is considered. The scenarios represent a means to assess the behavior of radionuclides in the environment in terms of their impact on potentially exposed individuals. A goal for designing the scenarios in this study is that if the hypothetical individuals are protected by specified dose limits, then it is reasonable to assume that others will be protected. The reference scenarios are standards against which levels of radionuclides in the soil at the Rocky Flats site can be measured.

Each scenario represents a single individual with unique physical and behavioral characteristics. These characteristics include variables correlated with dose, such as average breathing rate or dietary habits. Behaviors include time spent indoors and outdoors or eating foods from contaminated sources (e.g. family garden). Exposure scenarios provide assumptions about the nature and extent of possible contact that people might have with the site. Because this study is prospective in nature and has the goal of protecting potentially exposed people from radiation, it may be appropriate to consider biasing some of the scenario parameters in a way that would increase estimated annual dose. However, we recommend that this practice be limited to include only the possible; for example, an individual breathing 24 hours a day at the maximum rate for an Olympic athlete during a strenuous performance is not credible and should not be used to establish an average breathing rate. But it may be appropriate to estimate average breathing rates to include

periods of strenuous activity, provided the number and lengths of these periods do not exceed what is reasonable.

For the RSAL assessment, some of the parameters are breathing rates for various activity levels and ages, soil ingestion rates for children and adults, fraction of time spent indoors and outdoors, and the potential use of or exposure to contaminated water from the area. Selecting appropriate parameters for the scenarios depends upon a thorough review of the scientific literature and fully considering the uncertainty (or variability) distributions of the relevant parameters. We use a wide range of references and studies to compile information on parameters. Subsequently, we can generate a distribution of values and sample from the distribution, using Monte Carlo techniques. This process considers the available studies equally. The distributions can be characterized with a central value such as the median and some measure of the spread of the distribution, such as the standard deviation or the 5th and 95th percentiles of the distribution. In developing a particular scenario and considering variability of a parameter within the population studied, we can use a high (or low) percentile of the distribution as needed to extend protection to a larger fraction of a potentially exposed population with characteristics similar to those of the scenario subject. Once a parameter value is selected from our distribution of values for use in the scenario, the scenarios are considered fixed just as standards are fixed as a benchmark against which to measure an uncertain value. Behavioral characteristics should be plausible and relevant to the exposure situations and the radiation protection objectives.

Scenarios provide a technical basis for focusing on those pathways and characteristics that are most important in the dose assessment. For example, for plutonium in soils at Rocky Flats, the inhalation pathway will likely prove important. The inhalation or breathing rate affects the transport of airborne contaminants to the respiratory tract and also influences their deposition onto surfaces of the airways and in the pulmonary region. As a result, it is important to exercise care in selecting breathing rate values for each scenario. We have compiled data from numerous published papers to provide perspective in the selection of suitable breathing rates. For soil ingestion, we have reviewed various studies on the unintentional and intentional ingestion of soil by children and adults (e.g., Kimbrough et al. 1984, Calabrese et al. 1990). Simon (1998) developed scenarios based on an extensive review of the literature. The selection of input parameters will be described fully in the Task 3 report for this project. The historic approach for estimating breathing rates over a specified time period is to calculate a time-weighted-average of ventilation rates associated with physical activities of varying time durations. A second approach for determining breathing rates for various populations is based on basal metabolism and measured food-energy intakes and energy expenditures. There is much variability in breathing rates with activity level and age and thus, it is more defensible to use a distribution of values from which to select the input breathing rates (using a high percentile, for example) for an individual scenario.

RAC is evaluating the three scenarios described in the report, *Action Levels for Radionuclides in Soils for the Rocky Flats Cleanup Agreement*, dated October 31, 1996 (DOE/EPA/CDPHE 1996), along with additional scenarios that we have proposed and described at the monthly Radionuclide Soil Action Level meetings. RAC believes strongly that it is important to describe the process behind the development of the scenarios, to provide the panel with a broad range of scenarios for evaluation, and to consider a number of likely scenarios before final scenarios are selected for the project. In our discussions with the panel, we have used several breathing rate studies as examples of the kinds of data that will be used to develop

uncertainty distributions for key parameters. In these meetings, we described the step-wise process to show how breathing rates can be selected based on activity levels and age, and how these values are summed over a specified time period (e.g. hour, day or year) to yield an annual breathing rate. This demonstration was important to understand that an annual inhalation rate for an airborne radionuclide is based on a weighted average rate, where the weights are determined from the times spent in different activities and at indoor or outdoor locations throughout the day.

We consider the three scenarios outlined in the current Rocky Flats Cleanup Agreement as workable scenarios for the current project. We have designed additional scenarios, too. In some cases we have proposed scenarios with only minor variations from the three current scenarios in the cleanup agreement. For others, we have outlined scenarios with different assumptions about lifestyles and living conditions. Once again, the objective in developing the scenarios is based on the rationale that if the hypothetical individual in the scenario is protected by specified dose limits, then it is reasonable to assume that others will be protected. During the course of designing the exposure scenarios, we had proposed seven additional scenarios. After many discussions with the panel, we focused on four of the proposed scenarios for future RSAL work. The exposure scenarios that are under consideration are described briefly here, beginning with the current Rocky Flats Cleanup Agreements scenarios. Table 2.3-1 summarizes some of the parameter values for those scenarios.

1. The future residential exposure scenario assumes that an individual resides onsite all year and grows and consumes homegrown produce. This person would be exposed to radioactive materials in soils by directly ingesting the soils, by inhaling resuspended soils, by external gamma exposure from contaminated soil and airborne radioactivity, and by ingesting produce grown in contaminated soil. This scenario is from the current Rocky Flats Cleanup Agreement.
2. The open space exposure scenario assumes the person visits the site 25 times per year for recreational purposes, spending 5 hours per visit at the site. The person would be exposed to radioactive materials in the soil by directly ingesting the soils, by inhalation of resuspended soils, and by external gamma exposure from the soils and airborne radioactivity. This scenario is from the current Rocky Flats Cleanup Agreement.
3. The office worker exposure scenario represents an individual who works a 40-hour per week, 50-week per year job indoors in a building complex at the site. It is assumed that this person would be exposed to radioactive material in soils by directly ingesting the soils, by inhaling resuspended soils, and by external gamma exposure from soils and airborne radioactivity. This scenario is from the current Rocky Flats Cleanup Agreement.
4. The resident rancher scenario assumes future loss of institutional control. The rancher is raising a family, maintaining a garden and leading an active life at the site, spending 24 hours per day, 365 days per year or 8760 hours at the site. Of that time, over 40% is spent out of doors. The potential pathways of exposure for this person include inhalation; eating produce from garden irrigated with groundwater, direct soil ingestion from outdoor activities, and direct gamma exposure from the soils and airborne radioactivity. The annual breathing rate is 10,800 m<sup>3</sup> per year, based on a time-weighted average of breathing rates and activity levels as described during the monthly RSALs meetings. *RAC* proposed this scenario for consideration at the January 1999 RSAL meeting.
5. Infant in rancher family is 0 to 2 years of age, and onsite 24 hours per day, 365 days per year, or 8760 hr/year. The infant's potential pathways of exposure include inhalation, some direct soil ingestion from outdoor activities, and direct gamma exposure from soils and airborne radioactivity. *RAC* proposed this scenario for consideration at the January 1999 RSAL meeting.
6. The child of the rancher family is assumed to be 5 to 17 years of age, and onsite 24 hours per day, 365 days per year, or 8760 hr/year. The potential pathways of exposure include inhalation, eating produce from garden irrigated with water from a stream on the site, direct soil ingestion, and gamma exposure from soils and airborne radioactivity. *RAC* proposed this scenario for consideration at the January 1999 RSAL meeting.
7. The current onsite industrial worker scenario assumes a person works onsite 8\_ hours per day, 5 days per week, 50 weeks a year, or 2100 hours per year. It is assumed that 60% of the worker's time is spent outdoors. The potential pathways of exposure for this person include inhalation, direct soil ingestion from outdoor activities, and direct gamma exposure from the soils. The annual breathing rate is 3700 m<sup>3</sup> per year, based on a time-weighted average of breathing rates and activity levels for the time spent onsite. *RAC* proposed this scenario for consideration at the February 1999 RSAL meeting.

**Table 2.3-1. Summary of Key Scenario Parameter Values for DOE and RAC Scenarios**

Parameter	Current DOE/EPA/CDPHE scenarios			RAC recommended scenarios			
	Resident	Open space	Office worker	Nonrestrictive	Restrictive		
				Current site industrial worker	Resident rancher	Infant of rancher (new-born-2 y)	Child of rancher (5-17 y)
Onsite location				Present industrial area	East of present 903 Area	East of present 903 Area	East of present 903 Area
Time on the site ( $\text{h d}^{-1}$ )				8.5	24	24	24
Time on the site ( $\text{d y}^{-1}$ )				250	365	365	365
Time on the site ( $\text{h y}^{-1}$ )	8400	125	2000	2100	8760	8760	8760
Time indoors onsite ( $\text{h y}^{-1}$ )				900	3500	7740	6600
Time indoors onsite (%)	100	100	100	40	60	90	75
Time outdoors onsite ( $\text{h y}^{-1}$ )	0	0	0	1200	5300	860	2100
Time outdoors onsite (%)	0	0	0	60	40	10	25
Breathing rate ( $\text{m}^3 \text{y}^{-1}$ )	7000	175	1660	3700	10000	1900	8600
Soil ingestion (g)	0.2 for 350 d	0.1 per visit for 25 visits per y	0.05 for 250 d	0.20 for 250 d	0.20 for 365 d	0.20 for 365 d	0.20 for 365 d
Soil ingestion ( $\text{g y}^{-1}$ )	70	2.5	12.5	50	75	75	75
Irrigation water source	Ground-water	NA <sup>a</sup>	NA	NA	Ground-water	NA	NA
Irrigation rate ( $\text{m y}^{-1}$ )	1	NA	NA	NA	1	NA	NA
Onsite drinking water source	no	no	no	no	Ground-water	NA	NA
Drinking water ingestion ( $\text{L d}^{-1}$ )	NA	NA	NA	NA	2	NA	NA
Drinking water ingestion ( $\text{L y}^{-1}$ )	NA	NA	NA	NA	730	NA	NA
Fraction of contaminated homegrown produce	1	0	0	0	1	0	1
Fruits, vegetables and grain consumption ( $\text{kg y}^{-1}$ )	40.1	NA	NA	NA	190	NA	240
Leafy vegetables ( $\text{kg y}^{-1}$ )	2.6	NA	NA	NA	64	NA	42

<sup>a</sup> NA = not applicable.



### 3. SITE CONCEPTUAL MODEL

By the term *site conceptual model*, we mean those features of the site that may be explicitly represented by mathematical models for the purpose of predicting dose and deriving soil action levels. The site conceptual model includes the source of the radioactivity, which in this case is the soil on the site with residues of radionuclides that with levels that exceed background by detectable amounts. The model considers the ways in which these radionuclides can deliver dose to people who might come onto the site, and mechanisms by which the radionuclides will move over time from surface soil into other environmental media (environmental pathways), where they may expose people. Thus, the scenarios must be considered part of the site conceptual model, to the extent that they define the receptors and exposure modes (e.g., inhalation, ingestion, or external exposure). The site conceptual model is less detailed than the mathematical models that provide specific formulas for calculating the behavior of the radionuclides over time (dynamic models) and for estimating dose from radionuclide concentrations in environmental media (dosimetric models). It provides a framework within which the mathematical models are organized. Sometimes the term is used to include all parametric information necessary to perform dose calculations. Some of the computer programs that perform the calculations have user-friendly modules that elicit from the operator the information that defines the conceptual site model (RESRAD, MEPAS, GENII). This section gives an overview of the *RAC* conceptual site model for radionuclides in soil at the Rocky Flats site.

Soil action levels are defined in terms of dynamic models that simulate the movement of radionuclide residues in soil through environmental media. They also depend on exposure scenarios, dosimetric models and data, and scenario-specific annual dose limits. The environmental models consider pathways that the radionuclides will follow from the soil to the potentially exposed individuals described by the exposure scenarios. The term *pathway* refers to the succession of environmental media through which the radionuclides move (for example, soil to air, soil to air to garden produce and pasture grass, or soil to surface water runoff to stream). We use the term *exposure mode* for the manner in which the exposure to body organs and tissues occurs. Inhalation, ingestion, and absorption through the skin are modes of intake that lead to exposure from an internally distributed source (internal exposure). External exposure is the result of a person's proximity to a contaminated medium outside the body (air, ground surface, water in which the person swims), such that gamma rays from the radionuclides in the medium deliver dose to the person's organs and tissues. Examples of pathways and corresponding exposure modes are inhalation of radionuclides that are resuspended from the ground surface; ingestion of contaminated soil, either directly or from produce; drinking contaminated surface water (e.g., from a stream that has received runoff from contaminated soil); and consuming animal products (meat or milk) from livestock that have grazed contaminated pasture or drunk contaminated water.

It is important to be as specific as possible about the nature of the models that simulate the movement of the radionuclides along the environmental pathways leading to possible exposure of people. There is no unique approach to the definition of these models: they can range from simple to complicated. The choice of definitions is usually indicated by experience, consideration of the site, and what is mathematically or computationally tractable. Pathways that can be shown to contribute negligibly to the endpoint of the calculation, relative to other pathways, can be omitted, but this must be done with care. Section 3.1 describes the pathways that are potentially relevant to the RFETS. The pathways depend on the exposure scenarios, which we described in Section 2.3. The models, coupled into a system, are treated as uncertain (principally through their parameters:

*parametric uncertainty*), and when we are given a set of measured or hypothesized concentrations of radionuclides in the soil, we apply Monte Carlo analysis to the sum of ratios to derive a distribution that tells us the probability that the dose limitations will be met.

### 3.1 Transport pathways

#### 3.1.1 Availability of residual radioactivity in surface soil over time

The behavior of the radionuclides in the surface soil over time is clearly important because of the temporal scope of the scenarios (1000 years). Surface soil with adsorbed radionuclides is entrained into the air by wind action (resuspension) and eventually deposits again on the ground. The processes of resuspension and deposition exist in a quasi steady state cycle, with radioactivity being carried into a region and depositing there and local radioactivity being resuspended and carried away from the region. Over time, this cycle can alter the spatial distribution of radioactivity at the surface. Radioactivity is also removed from the surface soil over time by the action of water, at rates that depend on the amount of precipitation, properties of the soil, and the chemical forms of the radionuclides. Some of the radioactivity moves horizontally (runoff) to streams, and the remainder leaches downward, eventually (except for radioactive decay) crossing the water table and moving into the aquifer. Whatever effect the transport by surface water or groundwater may have on the scenarios that are chosen, it is necessary to take into account the fact that the fraction removed from the surface is no longer available as a source of external exposure or for resuspension. It is important that the transport models deal credibly with this dynamic behavior and persuasively quantify the uncertainties associated with it.

Our approach to multimedia modeling emphasizes the effort to preserve mass balance and to avoid deliberate biasing of environmental concentration estimates. This approach goes hand in hand with our treatment of uncertainty distributions. An example of an approach that would violate this principle is to estimate loss of radioactivity from surface soil by runoff and leaching without accounting for the complementary depletion of radioactivity in the surface soil reservoir. Such calculations can be defended as conservative, but the loss of mass balance accounting generally introduces difficulty into the analysis and interpretation of uncertainty, and we prefer to avoid this difficulty. Our alternative is to try to put the conservatism into the uncertainty distributions, preserving mass balance and minimizing bias. We stress that these are general guidelines, which require interpretation for specific application.

Thus, our conceptual site model treats the soil at any location of interest as a (primarily) vertical reservoir capable of representing distributions of different radionuclide concentrations over time. The model considers variable partitioning of each radionuclide into an aqueous (dissolved) and an adsorbed (adhering to soil) component. The first component moves with water that infiltrates the soil; the latter component is attached to soil matrix and mobile particles. Material attached to the soil moves by (1) surface weathering of the soil and (2) transferring from adsorbed to aqueous state when unsaturated water infiltrates the vadose zone. Radioactive ions also move from the aqueous state to attach to available sites on the soil matrix. The partitioning is usually characterized by a coefficient written as  $K_d$ , with units ( $\text{mL g}^{-1}$ ). In environmental work,  $K_d$  is interpreted as the ratio at steady state of the radionuclide activity adsorbed on soil divided by the radionuclide activity remaining in solution. However, the steady state assumption is sometimes questionable in the

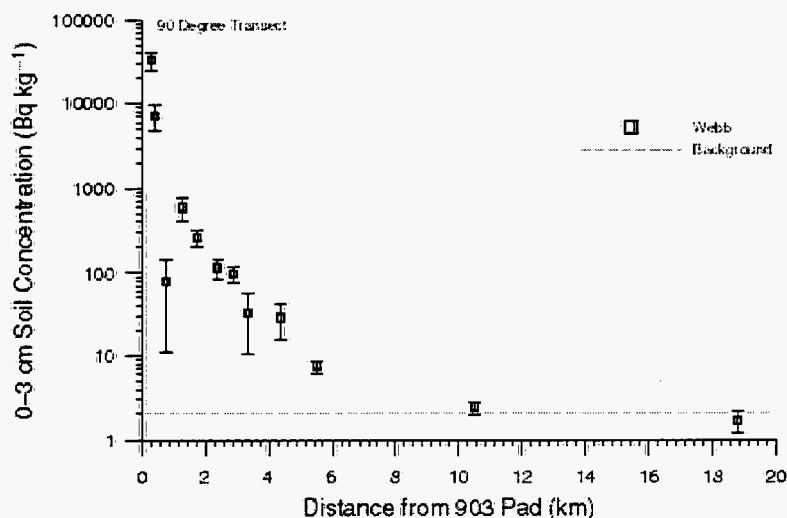
interpretation of process modeling. Narrower definitions of  $K_d$  are used in laboratory work, and criticisms of environmental soil modeling often turn on the use of this parameter and its different interpretations (Jirka et al. 1983).

We also need to mention the mechanism of colloidal transport, in which ions of the radionuclide attach to mobile submicron particles (colloids), which move by the action of water through interstitial spaces in soil and aquifers (Honeyman 1999). Recent investigations at the Nevada Test Site confirmed colloidal transport of  $^{239+240}\text{Pu}$  a distance of 1.3 km in groundwater. The  $^{240}\text{Pu}$ : $^{239}\text{Pu}$  ratio of the sample fingerprinted a particular underground nuclear test as the origin of the displaced plutonium (Kersting et al., 1999). The high affinity of plutonium for attachment to rocks has long supported assumptions of low mobility in predicting the movement of plutonium in soil and groundwater, but the introduction of colloidal transport models may eventually alter this pattern. No such explicit mechanism is included in any of the computer programs discussed in this report, and indeed, there is as yet no body of data that could credibly calibrate models of colloidal transport for the Rocky Flats site.

Given the initial amounts of radionuclides in the surface soil, the model predicts the evolving vertical distribution over time as the radioactivity is redistributed by the processes described above. At any subsequent time it is possible (in principle) to evaluate the predicted concentration in soil near the surface that would be available for resuspension, uptake through the roots of plants, direct ingestion, or exposing people to gamma rays from this external source. Not all computer programs handle the removal and redistribution mechanisms in the same way, and the results may differ.

### 3.1.2 Spatial disaggregation of soil

Contamination of the Rocky Flats reservation by some of the radionuclides of concern is far from uniform. Figure 3.1.2-1 shows the variation of  $^{239}\text{Pu}$  concentrations along a transect eastward from the 903 Area, plotted from data of Webb (1996). Litaor et al. (1995) show contour plots of  $^{239+240}\text{Pu}$  concentrations in the soil. Programs such as RESRAD proceed on the assumption of a uniformly contaminated area (subject to variation within a factor of 3). For some scenarios it could be desirable to subdivide the site area into some number  $P$  of plots, each of which can be treated as having a uniform concentration of each radionuclide, but with concentrations varying from one plot to another. Such subdivision might be of assistance in the planning for remediation, because the effects of reducing the most contaminated plots by various amounts can be studied explicitly. However, given the relatively small area of the most highly contaminated soil, we would be reluctant to recommend this refinement without careful evaluation of any factors that might seem to indicate it. We have included equations for area disaggregation near the end of Section 2.1 for the sake of completeness.



**Figure 3.1.2-1.** Plutonium-239 concentrations in soil (Bq kg<sup>-1</sup>) at RFETS along a 90° transect (eastward) from the 903 Pad area. The data are from Webb (1996).

### 3.1.3 Resuspended contaminated soil

The experience of *RAC* in the Rocky Flats Dose Reconstruction project indicates that the inhalation of resuspended soil that was contaminated by plutonium from the 903 Pad is a potentially significant exposure pathway. Its importance depends on how the scenarios are defined, primarily with respect to location relative to the locations of highest contamination of <sup>239+240</sup>Pu. In Section 2.3, we described a possible scenario that assumes eventual loss of institutional control of the site and that families establish homesteads west of Indiana Street, within the area most affected by the 903 Pad. Such a location (within the contour marked 10 Bq kg<sup>-1</sup>) would maximize the inhalation exposure to resuspended plutonium, given the prevailing westerly winds, whereas locations west of the RFETS near Highway 93 would correspond to lower inhalation doses. It seems clear that this exposure pathway must be considered, whatever the decisions about scenarios might be.

A serious problem in dealing with any exposure pathway that depends on resuspended soil is the uncertainty introduced into the calculation by the inexact characterization of the mechanisms. Resuspension occurs as a result of wind action on available soil particles, at a rate that depends on wind speed, gross characteristics of the ground surface (roughness of the soil, vegetation, and other objects), and characteristics of the soil, such as size distributions of the particles and tendency of the soil to form less-erodible crusts. The resulting air concentration (which determines exposure by inhalation and external exposure to gamma rays from the diffused particles) depends not only on the resuspension rate but also on stability parameters for the atmosphere, which establish a vertical profile of concentration, and on the deposition rate at which the airborne particles return to the ground. Local levels of contamination borne by the resuspended particles are diluted by particles that entered the air at various distances upwind from the contaminated site. The complexity of this environmental system guarantees large uncertainties in predictions of process-level models for which parameters are difficult or impossible to quantify by direct measurements. (We use

the term *process-level* to refer to models that are formulated in terms of the processes of fundamental physics, chemistry, and biology, as opposed to *empirical* models, which may summarize many complicated processes in a few directly measurable parameters. This is an oversimplification since most models are empirical at some level, but the distinction is sufficient for this discussion.)

Langer (1986) reports measurements of airborne  $^{239}\text{Pu}$  and airborne dust at heights of 1, 3, and 10 m from November 1982 through December 1984 (measurements at 3 m covered a shorter period). The dust-collection and wind-measurement apparatus was placed 100 m southeast of the former East Gate of the plant, near the 903 Pad, and less-detailed measurements of airborne  $^{239}\text{Pu}$  were also taken from three samplers near the former East Gate. Both the dust and radioactivity measurements give a crude indication of particle size distributions. A relatively long record of this kind provides what may be the most useful information for calibrating empirical models of resuspension from the field east of the 903 Pad, although this information is still very limited and must be applied with care. But these measurements do provide long-term averages of  $^{239}\text{Pu}$  air concentrations that likely approach the maximum for the site. These measurements implicitly take into account the dilution from upwind dust of low contamination, whereas modeling this dilution is a highly uncertain exercise. Krey et al. (1976) used air and soil sampling data from three sites in the field east of the 903 Pad to estimate that only 2.5% of the respirable dust came from local resuspension. This result cannot be considered generically applicable because of uncharacteristically high precipitation during the sampling period, but it does illustrate the point.

The computer programs under investigation approach the resuspension mechanism in one of three ways (in some cases, the user is offered an option of more than one method). (1) *Mass loading*, in which a measured or hypothesized concentration of airborne dust ( $\text{g m}^{-3}$ ) is multiplied by the local concentration of radionuclide on resuspendable soil particles ( $\text{Bq g}^{-1}$ ) to produce an estimate of airborne radioactivity concentration ( $\text{Bq m}^{-3}$ ). (2) *Resuspension rate* ( $\text{m}^{-2} \text{s}^{-1}$ ), which may be estimated as the air concentration of dust at a reference height ( $\text{g m}^{-3}$ ) times an average deposition velocity ( $\text{m s}^{-1}$ ) divided by the mass of resuspendable particles per unit area ( $\text{g m}^{-2}$ ). (3) *Resuspension factor*, which may be defined as the air concentration of dust at a reference height ( $\text{g m}^{-3}$ ) divided by the mass of resuspendable particles per unit area ( $\text{g m}^{-2}$ ). The resuspension factor has units  $\text{m}^{-1}$  (or  $\text{g m}^{-3}$  airborne per  $\text{g m}^{-2}$  of resuspendable soil particles) and is equal to the resuspension rate divided by the average deposition velocity. These three approaches to resuspension modeling must be handled with some care. Used without adjustment, they incorporate a tacit assumption that the calculated air concentration of radioactivity-bearing dust is undiluted by uncontaminated dust from upwind. The resuspension factor, for example, is interpreted as the air concentration of dust per unit areal mass of resuspendable particles. This very definition tempts one to impute the local air concentration entirely to the local supply of available particles. But under the usual windy conditions, this assumption would be approximately valid only for large uniform areas upwind from the reference location, and the same is true when the particles are assumed to be contaminated with radioactivity.

All three of these approaches require quantification from the analyst or from default values or formulas supplied by the programs. In this respect, the mass loading approach is perhaps the most direct, requiring as its parameter the very air dust concentration that we seek to estimate. The parameter estimate should be based on measurements taken at the site

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and averaged over as long a period as possible. The measurements of Langer (1986) indicate a mean total dust concentration of  $47 \mu\text{g m}^{-3}$  with standard deviation  $9.0 \mu\text{g m}^{-3}$  at the 1-m height for the period November 1982 through December 1984. This total quantity, however, includes a substantial fraction of particulate mass in a size range that is not regarded as respirable (59%). If the coarsest category of particles is discarded, the mean concentration is only  $19.2 \mu\text{g m}^{-3}$ . Most of the resuspended plutonium activity (81%) at the 1-m level is associated with the coarse (non-respirable) particles, leaving only 19% associated with respirable particles. We cite these data to illustrate the point that one should consider the question of the size distribution of the airborne dust and the distribution of plutonium activity over the airborne particles in order to make credible estimates of inhalation dose. The computer programs that implement mass loading do not exercise this judgment, although default values of some parameters may be supplied. Another complication is that air samplers lose efficiency as the particle aerodynamic diameter increases, and the efficiency loss is aggravated by the high wind events that cause much of the resuspension. Thus the measurements taken at Rocky Flats are subject to uncertainties of interpretation, and these uncertainties need to be quantified and incorporated into the calculation.

An approach to resuspension rate estimation is given by Cowherd et al. (1985) in an EPA report. Equations are provided for wind-driven resuspension associated with infinite and limited reservoirs of resuspendable particles. The parameterizations for the EPA models are given in detail, with instructions for coarse particle-size measurements in the field. The report also treats resuspension by mechanical means, such as vehicular traffic. The methods presented are intended to provide a "first-cut, order-of-magnitude estimate of the potential extent of atmospheric contamination and exposure resulting from a waste site or chemical spill, within the 24-hour emergency response time frame." Variants of these models are incorporated into MEPAS, with the necessary graphs and figures from Cowherd et al. (1985) reproduced in the MEPAS documentation. But by use of the front-end technique described in Section 4.1, these resuspension rate models can also be used in connection with other assessment programs, such as RESRAD, that do not implement the models. When this approach is taken, the resuspension model is programmed as part of the front-end script program, which calculates the resuspension rate and passes the information to RESRAD (or any other program with which a front end is used) through an input file. The EPA models will be compared with other resuspension approaches in the work for Task 5 (Independent Calculation) and a recommendation will be made. Our present reference to the variety of approaches is not intended to make the selection prematurely, but rather to stress the point that the available programs, as they stand, are merely tools. Whichever tool is chosen must be coupled with judgment, research, and due consideration of site-specific characteristics to produce a persuasive assessment.

The resuspension pathway affects several components of radiation dose: (1) inhalation, (2) external gamma dose from airborne particles, and (3) deposition onto foliar surfaces of food and fodder crops, thus affecting the ingestion dose from consumption of local produce and animal crops. For oxides of plutonium in the soil and a scenario such as the resident rancher or hypothetical future resident, that is located in the field east of the 903 Pad, the resuspension-inhalation exposure mode is likely to be the dominant component of annual dose. Therefore, it is much more important to formulate credible approaches to modeling the resuspension mechanism and quantifying its uncertainty for the Rocky Flats site than it is to

devote too much time and attention to debating relative merits of one computer tool over another.

### **3.1.4 Groundwater and surface water transport**

In calculating the proposed soil action levels (DOE/EPA/CDPHE 1996), the groundwater and surface water pathways were dismissed because (1) surface water features (Woman and Walnut Creeks) on the site are perennial and would not provide a reliable year-round water source for an individual living on the site and (2) surface aquifers underlying the site do not produce enough water for domestic or agricultural use. In addition, the aquatic food pathway was eliminated because the streams are not capable of sustaining a viable fish population. In this section, we will discuss these assumptions and the rationale behind them, and we will examine the ramifications of dismissing the groundwater and surface water pathways in the assessment.

**3.1.4.1. Overview of surface and groundwater hydrology at the RFETS.** Groundwater and surface water hydrology is discussed in the Sitewide Hydrologic Characterization Report (DOE 1995). The following material was paraphrased from this document and a White Paper that discussed the vertical contaminant migration potential at the RFETS (DOE 1996).

Three hydrostratigraphic units have been defined for the RFETS. Listed in descending order these units are the Upper Hydrostratigraphic Unit (UHSU), the Lower Hydrostratigraphic Unit (LHSU) and the Laramie-Fox Hills Aquifer Hydrostratigraphic Unit (LAHU). The UHSU consists of all surficial geological deposits and Arapahoe Formation sandstones that are in hydrologic connection with overlying surficial deposits, and weathered Laramie Formation claystone bedrock. These geologic units contain the uppermost aquifers underlying the RFETS. The LHSU consists of all unweathered Arapahoe and Laramie Formation bedrock and strata including upper Laramie claystones and confining beds. The LAHU consists of all unweathered lower Laramie Formation sandstone and Fox Hills Sandstone strata that comprise the regional Laramie-Fox Hills aquifer system. The LAHU forms the upper confining bed and the 7000+ ft thick Pierre Shale forms the lower confining layer.

The UHSU extends from the surface to a depth of about 35–60 feet. Small, mostly unconfined aquifers are present in the UHSU within the alluvium, colluvium, and valley-fill alluvium that make up the unit. Hydraulic conductivity in these units span 5 orders of magnitude. The geometric mean value for the Rocky Flats alluvium, colluvium, and valley-fill are  $2.06 \times 10^{-4}$ ,  $1.15 \times 10^{-4}$ , and  $2.16 \times 10^{-3} \text{ cm s}^{-1}$  respectively. These aquifers are not considered viable for drinking water or irrigation because their well yields are quite low, typically ranging from 0.05 to 2 gallons per minute in isolated areas. Water flow is typically from west to east-northeast and follows the surface topography. Aquifers terminate where they intercept the ground surface at incised surface drainage features such as Woman and Walnut Creek and at the contact between the Rocky Flats alluvium and bedrock unconformity. Surface discharge is typically manifested in the form of a seep. There is also vertical movement downward into the LHSU.

The LHSU is composed mainly of claystone and siltstone with a few discontinuous sandstone lenses. Thickness is estimated to range between 850–870 feet. Vertical migration of infiltrating waters from the UHSU into and through the LHSU is limited by the low

vertical hydraulic conductivity of this unit. Laboratory tests of core samples indicate a hydraulic conductivity ranging from  $1 \times 10^{-6} \text{ cm s}^{-1}$  near the top of the unit to  $1 \times 10^{-7} \text{ cm s}^{-1}$  near the bottom. Fracturing, however, can significantly increase the effective hydraulic conductivity in a relatively impermeable porous medium such as the LHSU. Fracture zones have been observed in the UHSU and LHSU and provide a viable means of moving groundwater from the UHSU to the Laramie–Fox Hills aquifer system. Faulting has also been postulated as a potential groundwater transport pathway from the UHSU and LHSU to the LAHU.

The LAHU is composed of fine to medium grained sandstone separated by a few claystone beds in the upper portion. Thickness ranges from 200 to 220 feet for the “A” and “B” sandstone that comprise the lower interval of the Laramie formation, and 80 feet for underlying Fox Hills sandstone unit. The Laramie–Fox Hills aquifer system is the target of most water wells in the vicinity of Rocky Flats because this aquifer provides sufficient water for domestic and industrial uses. Recharge to the aquifer takes place along the foothills west of the RFETS where the permeable sandstone beds of the formation are folded up and exposed. The permeable sandstone generally dips eastward toward the center of the Denver Basin.

Surface water features at the RFETS include Walnut and Woman Creeks and several ditches that provide irrigation water. Walnut and Woman Creeks are perennial and generally respond to seasonal fluctuations in precipitation, recharge, groundwater storage, and stream and ditch flow. In the past these creeks drained into and Standley Lake, respectively. As of 1992, Walnut Creek, which previously flowed into the Great Western Reservoir, was diverted around Great Western Reservoir. By 1996, Woman Creek no longer flowed from the site directly into Standley Lake.

**3.1.4.2. Implications of ground and surface water pathways on soil action levels.** In an analysis of the vertical contaminant migration potential at RFETS (DOE 1996) it was concluded that the upper Laramie Formation confining beds have a sufficient amount of hydrologic and geochemical integrity to provide long-term protection of the Laramie–Fox Hills Aquifer from contamination at the RFETS. After reviewing this document and its supporting calculations, we agree with their conclusion but do not see this as a reason to discontinue research in this area or to dismiss entirely groundwater issues at the RFETS. The analysis leaves open other potential water transport pathways, and the possibility of colloidal transport may be important. Most notably, these potential pathways include lateral transport in the UHSU and discharge to surface water features followed by migration to downstream reservoirs. Additionally, direct usage of the UHSU aquifers could also be considered. One may also argue that under an exposure scenario that assumes subsistence conditions, a water well that produces 2 gallons per minute (such as has been observed in the UHSU) would be adequate to provide drinking water and perhaps water for a few head of livestock and some limited irrigation. Failure to address these pathways quantitatively leaves open the question of their potential importance.

It is well beyond the scope of this project to address the groundwater pathway in any substantial way other than through a simple screening exercise. Sophisticated groundwater modeling is difficult and time consuming, requiring substantial quantities of field data to characterize subsurface hydrologic units. We examine a conservative calculation in order to address the question of whether or not the pathway can be ruled out of the current analysis. We activate the groundwater pathway model in the RESRAD simulations, using the site

conceptual model and parameter values developed and documented in the proposed soil action level document (DOE/EPA/CDH 1996). The RESRAD conceptual site model assumes that a scenario subject uses groundwater derived from the UHSU for drinking water and some irrigation. The default RESRAD water ingestion rate of 510 liters per year was used in the analysis. Parameter values used in the assessment were reviewed and appear to be reasonable based on the information provided in the hydrogeologic characterization reports (DOE 1995).

Results for Tier 1 Action Level (85 mrem) residential exposure scenario are shown in Table 3.1.5-1. Note that action levels changed only for  $^{241}\text{Am}$ ,  $^{241}\text{Pu}$ , and  $^{234}\text{U}$ . In the case of  $^{241}\text{Pu}$ , the ingrowth and ingestion of  $^{241}\text{Am}$  is what caused groundwater ingestion doses to outweigh doses from external sources and inhalation. In the case of  $^{234}\text{U}$ , ingestion doses are substantially higher than doses from external radiation. Dose from external radiation made up most of the total dose for  $^{235}\text{U}$  and  $^{238}\text{U}$ , and therefore groundwater ingestion doses had little impact. In the case of  $^{241}\text{Am}$ , ingestion doses are substantially higher than inhalation or external doses. The highest doses for radionuclides where inclusion of the groundwater pathway made a difference ( $^{241}\text{Am}$ ,  $^{241}\text{Pu}$ , and  $^{234}\text{U}$ ) occurred 202, 222, and 379 years from the start of the simulation respectively. Highest doses when the groundwater pathway was ignored occurred at year 0 except for  $^{241}\text{Pu}$ , which occurred 15 years from year 0. For the radionuclides whose action levels changed when the groundwater pathway was included, the differences in the times of maximum dose reflect the transit time from the source to the aquifer. For the radionuclide given the most attention ( $^{239}\text{Pu}$ ), the soil action level remained unchanged.

**Table 3.1.5-1 Soil Action Levels for the Residential Exposure Scenario at the 85 mrem Level Including and not Including the Groundwater Pathway**

Radionuclide	Soil Action Level without Groundwater Pathway (pCi g <sup>-1</sup> ) <sup>a</sup>	Soil Action Level with Groundwater Pathway (pCi g <sup>-1</sup> )
$^{241}\text{Am}$	215	110
$^{238}\text{Pu}$	1529	unchanged
$^{239}\text{Pu}$	1429	unchanged
$^{240}\text{Pu}$	1432	unchanged
$^{241}\text{Pu}$	19830	3370
$^{242}\text{Pu}$	1506	unchanged
$^{234}\text{U}$	1738	660
$^{235}\text{U}$	135	unchanged
$^{238}\text{U}$	586	unchanged

<sup>a</sup>. Source: DOE 1996a

The results of this exercise suggest that the rationale for dismissing groundwater as a viable pathway should perhaps be investigated further. The ongoing activities of the Actinide Migration Panel and other studies involving plutonium mobility should shed additional light on this subject. However, the results of these studies will not be available in time for completion of this work. For the purpose of calculating soil action levels, we will include the

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groundwater ingestion pathway for at least one of the scenarios using a model with a level of complexity similar to the one implemented in RESRAD. A more detailed evaluation is not possible with the time and budget constraints of this project. We use the principle that by protecting scenario subjects who live and use water onsite, we are protecting all other potential users because transport of activity away from the site will result in lower exposure concentrations because of dilution and dispersion.

As shown by the preceding example, the inclusion of the groundwater pathway had little impact on the overall soil action levels except for the radionuclides noted, and we expect that this will be true in future simulations because inhalation and external doses tend to outweigh ingestion doses for most nuclides. We should caution that the results this assessment of groundwater are subject to reinterpretation based on any new findings from actinide migration studies and additional investigations performed for site remediation purposes.

### 3.2 Exposure Modes

The exposure modes described in this section have already been mentioned in previous sections to illustrate exposure pathways. The basic modes are inhalation and ingestion (internal exposure) and exposure to an external medium containing beta- and (primarily) gamma-emitting radionuclides. Other possible modes for internal exposure are absorption of a radioactive compound through intact skin or introduction of radioactivity into blood or by contact of a radioactive chemical with an open injury.

All types of radiation from radionuclides are significant for internal exposure. For external exposure, the dominant radiation type of a radionuclide permits some generalizations. Alpha-emitting radionuclides are not ordinarily a significant external source. Some beta emitters in high enough concentration in close proximity to a subject for a sufficient time can produce short-term damage to the skin, but beta rays have limited penetration in tissue and their dose is usually confined to a layer within a few millimeters of the skin surface. Gamma emitters produce penetrating rays that are capable of delivering energy (dose) from an external source to all parts of the body. The magnitude of the gamma dose received depends on the concentration of the gamma-emitting radionuclide in the source medium, its energy spectrum (higher energy photons tend to distribute their energy more deeply in tissue than lower energy photons), the geometry of the medium, the duration of the exposure, and the distance of the subject from the source medium.

Practical dose estimation is accomplished by means of dosimetric databases, consisting mainly of *dose coefficients* (sometimes called *dose conversion factors*) and other factors that relate the various kinds of exposures to the dose received per becquerel (Bq) of a radionuclide taken into the body or the dose rate per unit concentration of a radionuclide in an environmental medium to which a subject is exposed. These dosimetric factors are computed by specialists, who use models of physical and biological processes to simulate the interaction of radiation with tissue and the dynamics of metabolism of radioelements and compounds by organs of the body. Dose may be estimated by multiplying an intake rate (such as the breathing rate of someone inhaling a radionuclide suspended in the air, or the daily amount of a radionuclide that is being consumed with water and food) by the appropriate dose coefficient (intake per day times effective dose per unit intake = committed dose per day) and by the duration of the exposure; or by multiplying the concentration of a radionuclide in an exposure medium (such as the air) by a dose factor that gives dose rate per unit

concentration of the radionuclide in air (= dose received per day) and by the duration of exposure. There is a difference of interpretation between the internal and external dose estimates just indicated by example. When a radioactive chemical is taken into the body, time is required for the chemical to be translocated to the internal organs, metabolized, and excreted. During this process, the organs and tissues are exposed to the radionuclide and receive dose, but the amount of dose depends in part on the time required for metabolic processes and radioactive decay to remove the material from the body. For some radionuclides, the time over which the dose from a single intake accumulates is measured in years, and accordingly, we speak of the *committed* dose that will result from the intake (although some radionuclides have short half-lives and are quickly removed by radioactive decay, and some radioelements and compounds have biochemical properties that cause them to be rapidly removed from the body). External dose, on the other hand, is delivered at a practically instantaneous rate as long as the subject is exposed to the medium in which the radionuclide (or other source) is distributed.

Dose can be estimated for any organ that absorbs energy from ionizing radiation. The *effective dose* is a concept promoted by the International Commission on Radiological Protection (ICRP), which gives a nonlocalized definition of dose that is roughly proportional to the risk of radiation-induced cancer in *some* organ or tissue; the proportionality is achieved by weighting the equivalent dose to each internal organ with a relative risk coefficient for the organ (ICRP 1977). The effective dose is not to be confused with whole-body dose, which lacks this more refined connection to cancer risk.

All radiological assessment computer programs that we consider have databases of internal dose coefficients and external dose rate factors for each of a large library of radionuclides, including the relevant plutonium and americium isotopes for the Rocky Flats site and the decay products. The databases are similar among the programs, to the extent that they are based on published guidance from the International Commission on Radiological Protection (ICRP), particularly for internal dosimetry. The tables of internal dose coefficients provide alternative sets of numbers for different element-specific solubilities for both inhalation and ingestion. External dose rate factors are taken from Federal Guidance Reports such as Eckerman and Ryman (1993).



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## 4. CANDIDATE COMPUTER PROGRAMS

### 4.1 Introduction

We originally selected for review five candidate computer programs that were developed for environmental risk assessment. The criteria for selection included the following:

- (1) Presumed correctness of the models implemented by the programs, as indicated by their general acceptance, logical correspondence with features of the site, treatment of exposure pathways, and consistency with the available site data
- (2) Amount and quality of validation that has been carried out and documented, and suitability for validation with local data
- (3) Quality of program documentation and availability of source code
- (4) Platform (i.e., computer and operating system) and (if source code is made available) programming language
- (5) Flexibility of operating features, particularly the possibility of bypassing the user interface in order to invoke the computational part of the program and specify input and output files from the command line.

We confined the selection to programs that are generally comparable to RESRAD and that are (or are likely to be) widely used. In accordance with the contract, we include RESRAD as one of the candidates (it would have been included in any case). The other programs are MEPAS, GENII, MMSOILS, and DandD. All five have been (or are being) developed under sponsorship of one or more federal agencies, and to the best of our knowledge, the development project for each program has been carried out under formal quality assurance (QA) protocols.

The five criteria listed above were formulated before we made final decisions about the selection and before we began to procure code and documentation, install the executables on computers, and explore ways in which each program could be used. We have been allowed to see the source code for RESRAD. Source code is distributed with MMSOILS and GENII. We were not granted access to source code for MEPAS, but some version of DandD source code may be available, though it was not yet available to us as this report was prepared. It is not and was never our intention to carry out detailed reviews at source code level. We were primarily concerned with ways of executing the programs as indicated in item (5). We felt the need to be able to use scripting programs to manage Monte Carlo selection of parameter sets, to permit initialization calculations of relative abundances of plutonium and americium isotopes, and to invoke each of the five programs from the command line through the scripting program, passing each parameter selection prior to execution. This mode of operation permits us to apply Monte Carlo methods to programs that have no internal provision for them. Even with RESRAD, which has a beta-test version of a Monte Carlo facility, the built-in version is not entirely satisfactory for our purposes. RESRAD, MMSOILS and GENII are adaptable to this approach.

All five of the programs can be installed and executed under some version of the Microsoft Windows operating system (95 or NT, and presumably 98; by compiling the FORTRAN source code, we have executed MMSOILS under the Linux operating system, which is a variant of Unix; the instructions downloaded with MMSOILS indicate the installation procedure for DOS or Windows). Thus all of the programs would be widely accessible.

Comparative studies of three of these programs (RESRAD, MMSOILS, and MEPAS) have been made by groups including members who participated in their development (Laniak et al. 1997; Mills et al. 1997).

As this Task 2 report was nearing completion, a relevant report by the National Council on Radiation Protection and Measurements was released (NCRP 1999). NCRP Report No. 129 extends the NCRP series on screening limits, and this latest installment directly addresses radiation doses from exposure to contaminated surface soils. The report hypothesizes eight exposure scenarios and provides extensive tables of parameter values, screening limits, and dose estimates, with estimated uncertainties. The timing of the release of NCRP Report No. 129 did not permit us to prepare any substantial commentary on its relationship to this project. The reader should bear in mind that NCRP Report No. 129 is about screening limits. These limits are based on an annual effective dose limit of 25 mrem for exposure to a particular site, and this limit refers to the maximum dose to any exposed individual within a period of 1000 years. The screening limits (units Bq kg<sup>-1</sup>) correspond to soil action levels for the NCRP-defined exposure scenarios, although the "action" envisioned in the screening context would likely consist of some level of site-specific reassessment. As we move forward with the project, we will continue to evaluate NCRP Report No. 129 for any implications that its methods and data might have.

This project's Request for Proposals (RFP) expressed concern for validation of the programs to be considered. We feel that it is necessary to go into some detail about procedures usually (but not always) termed *validation* and *verification* as applied to models and computer programs. We wish to be as clear as we can about what can and cannot be assumed with regard to procedures that are labeled with these terms.

#### 4.1.1 Verification of Computer Programs

We believe it is necessary to make a distinction between the terms *validation* and *verification* (and the corresponding verbs) when they are applied to computer software. We need to go into some detail about these concepts, because one term is frequently used in place of the other, and usage is not uniform. Validation enters prominently into the project contract, and we need to strive for a clear understanding of what is possible in this regard and what is not.

Verification refers to procedures that try to ensure that a program is correctly coded, which is to say that it faithfully implements the mathematical descriptions of the models that define it, that it correctly translates input information furnished by the operator into all parameter values and control information required for calculations, that it detects inadmissible entries in the input, and (given admissible input) that it produces output that is in correct correspondence with the input. A process of verification would be perfect if one could somehow prove that for any set of admissible input data, the program will provide the output that the mathematical models and the algorithms imply, and that any inadmissible input data will be flagged. Computer scientists study verifiability as an academic subject and endeavor to develop methods for proving that a given program does what it is intended to do. As a practical matter, verification is an empirical process of systematic testing at many levels during development, investigating apparent anomalies reported by users, and making corrections as required. A reality that must be accepted is that all complex software is imperfect to some degree; in the vernacular of the trade, it has "bugs." The amount and

quality of testing that a programming project can afford depends on the intended use of the software and the seriousness of the probable consequences, should it malfunction. When failure may cause injury, loss of life, property damage, or misallocation of significant sums of money, then extensive testing is necessary, and its cost must be supported. Different levels of criticality are formalized in QA procedures for software. The length of time a computer code has been used is perhaps a more important factor. Codes with a long track record of performance have had many of their bugs pointed out by users and corrected by the developers. Users have also compared code output to their own hand calculations or results from other codes that perform comparable calculations. Taking this longevity into account, a user may gain confidence that the code is performing in a satisfactory way.

#### 4.1.2 Validation of Computer Programs

Validation is an entirely different concept from verification. Validation also entails testing, although it is testing of a different kind. We will point out here that validation also has a special meaning in the realm of computer code quality assurance (QA). In this context, validation of a program is the process by which all of its modules are tested together, as a whole. The test is satisfactory if the requirements identified in the software specification and requirements documents are met. The present discussion does not address this narrower meaning of computer code validation. Instead, we consider model validation — that is, the collective ability of the mathematical models encoded in the computer program to predict the behavior of contaminants in the environment.

Abstractly, a computer program is considered valid for a specified predictive application if its results can be shown always to approximate acceptably their real-world counterparts. Thus, if we know how much uranium was released from a nuclear facility during a particular period and we have air monitoring data for uranium for that period, then using the known releases and an atmospheric diffusion model, we can predict air concentrations at the locations of the monitoring stations and compare the predicted concentrations with the measured values (if we assume that no other source of airborne uranium is distorting the measurements). If the approximation is acceptable, we have validation of the model for the period and the monitoring locations. Like verification, validation is necessarily imperfect (indeed, in a strict sense, it is impossible; *invalidation* would be decisive if the predictions and observations did not agree, but a claim of *validation* is merely a finding of no contradictory evidence, which leaves open the question of whether such evidence still might exist). The testing is specific rather than general: it is useless to declare that a computer program “has been validated,” without specifying the particular comparisons that have been carried out. In our experience, validation of software that is applied to environmental assessments needs to be site-specific, and conclusions of any comparison must be drawn very cautiously. In the uranium example just mentioned, we might be willing to extend our tentative confidence in the model to other locations within the assessment domain that are not much farther from the facility than the monitoring stations, and we might accept predictions for other periods when we have data on releases but no monitoring data. But if we used the model to predict deposition of uranium on the ground near the facility without having measurements of uranium concentrations in the soil, for example, we would probably be going beyond the validation exercise that we have described, and although deposition rates are proportional to

air concentrations, the predicted deposition rates would not gain the same credibility from the exercise as the predicted air concentrations.

The interpretation of validation exercises is never entirely clean. Consider once again the example of predicting uranium concentrations in air. Our calculations involve more than the computer program: there are the estimates of the uranium releases, which are subject to error, and there are meteorological data, which may or may not be accurate for the locations and period for which they were applied. It is possible for errors in the data to compensate for errors in the model, giving apparently good results and encouraging us to trust a program that intrinsically might not be an acceptable representation of the processes we are simulating. Alternatively, errors in the data could make an acceptable model look bad. When we must depend on data that are available, it is practically impossible to implement rigorous designs that might remove these confounding effects. We must generally be satisfied with making as many tests of two or more correlated functionalities (e.g., diffusion and deposition, if we have data for both) as possible, in the hope that good agreement of predictions and data will be persuasive at an admittedly subjective level.

There are processes for which validation would require measurements spanning impractically (or impossibly) long time intervals. The rate of removal of plutonium from surface soil is a relevant example for which many years of data — possibly a century or more — at the same set of locations would be required for validating some relevant parameters of RESRAD for Rocky Flats, when the intent is to use scenarios spanning 1000 years.

The computer programs themselves sometimes thwart validation efforts. When the computed results must be interpreted as spatial or temporal averages, and the only data available for comparison are specific to a small part of the assessment domain, or represent only a brief period, then the comparisons may be meaningless. There are instances when the program does not output those quantities that would be used for comparison; this is often the case when the desired endpoint is dose or risk, but for validation, we may need predicted concentrations of radionuclides in air, soil, or water.

We do not wish to convey the impression that we believe the kinds of comparisons usually called *validation* are not important. On the contrary, we include them whenever we believe they can contribute to the level of confidence we and others might have in the application of a computer program that we are using. But we stress the point that in no circumstances should any computer program be considered “validated” in the abstract so that its output is implicitly trusted. In our view, validation is a process involving a specific problem (e.g., an environmental assessment involving specified scenarios and pathways at a particular site), analysts, other interested parties, a computer program, and sets of data that can be interpreted as exogenous inputs, parameter values, and outcomes of processes simulated by the computer program. When the people involved can agree that persuasive correlations of predictions and data have occurred, then we may consider the program to be validated with respect to the processes, data, and other specifics (e.g., location and time) that have been tested, but always bearing in mind that our sense of caution should increase as we apply the program to conditions different from those of the tests. A decisively negative result of a validation process is also a useful result (although often considered an inconvenient one), in that it points to something that is wrong about the program, the data, or the interpretations that have been made; but such a result usually produces further analysis and eventually another set of tests. And we must add that in some cases, a satisfactory validation

(by which we mean that it reaches an accepted result, affirmative or negative) may not be possible.

Given the inherent difficulties of validation, one often has to supplement it with other approaches. Uncertainty analysis, appropriately applied, leads to results that quantify possible errors that derive from lack of knowledge or variability of parameters. Uncertainties about the proper structure of the model are more difficult. The temptation is to try to broaden the "space" of models from which the one in question has been drawn and to extend the uncertainty calculation to a representative set of possible replacements from this space of models (Draper 1995). But this approach has immense conceptual and technical difficulties. A more pragmatic option is to accept model structures that have been affirmatively validated in a variety of similar problems as provisionally correct but with magnitudes of uncertainty indicated by a broad range of experience. For example, in atmospheric diffusion calculations, the straight-line Gaussian plume model is widely used in environmental applications, although this model is based on assumptions that are technically too simple for most of those applications. But experience and experiment indicate that for particular categories of predictive use, the Gaussian plume can be associated with corresponding uncertainty distributions. For example, from a review of numerous sets of experimental data, Miller and Hively (1987) concluded that for flat terrain, away from coastal areas, the Gaussian plume can predict annual averages of concentrations within a factor of two 90% of the time out to a distance of 10 km and within a factor of four with 90% probability somewhat beyond that distance. Such information must be applied with care and skill, but it provides an empirical representation of atmospheric diffusion and some level of confidence in the model; the cost is the stated uncertainty. This illustration, however, should not be interpreted to mean that the straight-line Gaussian plume model is applicable with knowable uncertainty to any atmospheric diffusion problem. It is not, and we know of no model that is.

Some scientists object to the use of the terms *verification* and *validation* (which are sometimes used interchangeably in the sense in which we have used the latter) in connection with numerical models of complicated and incompletely understood open systems (i.e., depending on incompletely specified initial and boundary conditions and exogenous information). Oreskes et al. (1994) criticize definitions given by DOE and the International Atomic Energy Agency (IAEA) in which validation implies that a model or program correctly represents a physical system, and these authors correctly emphasize that such a claim "is not even a theoretical possibility." They would prefer the use of more neutral language, replacing *verification* and *validation* with terms that indicate judgment and contextual interpretation of model performance.

#### 4.2 RESRAD

The U.S. Department of Energy (DOE) and Argonne National Laboratory (ANL) have developed the computer program RESRAD (RESidual RADioactivity) for the purpose of performing calculations related to meeting the Department's criteria for residual radioactivity. The program originally (1989) implemented site-specific guidelines (called soil action levels in this report) based on a dose assessment methodology consistent with DOE Order 5400.5 (DOE 1993).

The most recent version of RESRAD for which we received executable code from ANL (Version 5.82, transmitted to us in October 1998) differs in some important respects from older versions that are still in use; in particular, it differs from the version of RESRAD that was used in the preparation of the action levels document (DOE/EPA/CDPHE 1996). Thus RESRAD is not uniquely defined for this study, and we must distinguish among versions of the program in discussing it and in considering it for possible use. In Sections 4.4.3 and 4.6.3, comparisons of GENII and RESRAD, and DandD and RESRAD, respectively, were made using Version 5.61 of RESRAD.

#### 4.2.1 RESRAD overview

The manual for Version 5.0 (Yu et al. 1993), which was distributed with Version 5.82, does not correspond to the more recent graphic user interface (GUI) implementation. A user's guide for the latter, which is a replacement for Chapter 4 in the manual (Yu et al. 1993) is now available from ANL or from the web site <http://www.ead.anl.gov/resrad>. DOE has directed ANL to discontinue distribution of RESRAD versions for the DOS operating system, the most recent of which was Version 5.62. Some of the information we received seemed to suggest that there might be incompatibilities of DOS versions with contemporary Windows operating systems. However, we have tested Version 5.61 in a command window under Windows NT and encountered no problems with it. However, a major algorithmic change affecting the Windows versions of RESRAD (beginning with Version 5.75) has been made in the area factor for the resuspension of soil particles (Chang et al. 1998). The difference in predicted doses and soil action levels can be significant. We will discuss the change in a later section.

The manual for RESRAD (Yu et al. 1993 with replacement for Chapter 4) is written with reasonable clarity and is a good compromise between encyclopedic detail (which nevertheless would sometimes prove helpful) and readability. Five chapters (and a sixth of references) provide introductory material, a rather good discussion of the pathway analysis implemented by RESRAD, a definition and discussion of *guidelines* for radionuclides in soil (the RESRAD and DOE term for what this report has called soil action levels), a user's guide for the program keyed to the earlier version 5.0 (for which the previously mentioned replacement is available), and a discussion of the "As Low as Reasonably Achievable" (ALARA) process. A set of appendices provides detailed information on the models and approaches incorporated into RESRAD (some of the information in Appendix B is made obsolete by the presentation of Chang et al. (1998)). A substantial index should be high on the list of priorities for this manual, and we would recommend breaking the user's guide (Chapter 4) into a separate document, which can more easily be kept current with new releases (a replacement for this chapter has been issued for the Windows versions of RESRAD).

The basic model that RESRAD implements is the family farm or homestead with soil and possibly surface water and groundwater contaminated with residual radionuclides. However, pathways (inhalation, external gamma radiation from soil and airborne radioactivity, soil ingestion, drinking water, ingestion of vegetables, meat, and milk) can be individually switched on or off to permit the treatment of other scenarios. RESRAD begins with an assumed initial mixture of radionuclides in an unsaturated soil compartment called the contaminated zone (CZ), which is a slab of finite area that may or may not be isolated from

the surface by a cover layer (for applications at the Rocky Flats site, the contaminated zone has no cover layer; it is assumed to extend from the surface to a depth of 15 cm). In general, the contaminated zone is a proper subregion of the unsaturated zone. The unsaturated zone may be partitioned into as many as five independently parameterized strata to simulate soil zones with different transport characteristics, and the contaminated zone may be contained in one of these layers or intersect two or more of them. Initial radionuclide concentrations of radionuclides in the saturated zone (groundwater) may also be included. RESRAD simulates the removal of radioactivity from the contaminated zone by leaching, moving it vertically into groundwater, and by runoff into streams or ponds. If the water pathway is activated, contamination of drinking water at a central or peripheral well site is estimated, and contaminated groundwater may be mixed with contaminated surface water for drinking, household use, irrigation, and watering livestock.

Radioactivity from the contaminated zone may be resuspended by a mass-loading model; separate resuspension pathways are implemented for inhalation exposure and for foliar deposition on crops and animal fodder. External doses from exposure to gamma emissions from the contaminated zone and the resuspended contaminated soil particles are estimated. Beginning with Version 5.60, the external radiation field calculations incorporated refinements for the finite area and volume (with possibly irregular shape) of the contaminated zone, in contrast to previous methods that assumed semi-infinite distributions of radioactivity in source media (Kamboj et al. 1998).

As we have pointed out in Section 3.1.3, resuspension of contaminated soil at Rocky Flats should not be treated as a routine matter, and there are several approaches that need to be considered. As noted above, versions of RESRAD beginning with 5.75 represent the area factor for resuspension in a more elaborate way that potentially produces dose and soil action level estimates that differ significantly from those of earlier versions. RESRAD does not include a conventional atmospheric transport model for estimating remote air concentrations and foliar deposition (e.g., at locations away from the contaminated zone on the Rocky Flats site), but the manual gives some guidance for carrying out auxiliary calculations if they are required. However, the new approach to the area factor for resuspension (Chang et al. 1998) does make use of the Gaussian plume model, but the use of this model is confined to estimation of the area factor and thus effectively applies the Gaussian plume model only to a receptor at the downwind boundary of the contaminated zone.

Ingestion pathways for crops, meat, milk, and direct ingestion of soil are included in RESRAD, with the assumption that the food for people and fodder for animals are grown in the soil of the contaminated zone. Thus these plants are subject to radionuclide uptake through the roots and surface contamination by foliar deposition by resuspended contaminated soil. The dose conversion factors that are applied to the ingestion pathways correspond, by default, to the most readily absorbed (i.e., most soluble) form of each radionuclide that is available in the database. This means that the largest available value of the gut absorption parameter  $f_1$  is used. For isotopes of plutonium, the RESRAD default assumption is  $f_1 = 10^{-3}$ , which means that approximately 1/1000 of the plutonium activity that passes through the small intestine is absorbed into body fluids and translocated to systemic organs, principally bone. Less soluble forms of plutonium, such as oxides, would correspond to  $f_1 = 10^{-5}$ . The analyst can decline the RESRAD default and opt for a dose conversion factor with a smaller value of  $f_1$  from the database (provided one is available;

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$10^{-5}$  is available for plutonium). For material incorporated into plant tissue by root uptake, an argument may be made that the process favors an ionic state of the nuclide, but for oxides of plutonium that deposit on plant surfaces,  $f_1 = 10^{-5}$  is likely the more realistic choice. However, the assumption of the more soluble form is a common one for screening calculations.

Area factors for crops, meat and milk account for fractions of the quantities consumed that come from inside the contaminated area, as opposed to the remainder, which is assumed to be produced elsewhere and uncontaminated. The default assumption is that at most half of the produce consumed is raised within the contaminated area; for meat and milk the fraction increases linearly to 1.0 as the area of the contaminated zone increases to 20,000 m<sup>2</sup>. The analyst can change these default values.

Foliar deposition and retention is based on a simple steady-state model. The deposition rate is computed as the air concentration of radioactivity and a deposition velocity that depends on the assumed physico-chemical state of the material (0 m s<sup>-1</sup> for relatively inert gases, 10<sup>-2</sup> m s<sup>-1</sup> for halogens, and 10<sup>-3</sup> m s<sup>-1</sup> for everything else; these values appear to be hardwired into the program). An interception fraction determines how much of the deposition flux is retained on the plant (this value may be changed), and the amount is decreased over the holdup time according to a first-order weathering rate parameter with a default value that corresponds to a half-time of about 2 weeks. The model also depends on the crop yield for the type of food (produce, fodder for meat, or fodder for milk). The air concentration on which this pathway depends is based on a mass loading model that is similar to but evaluated separately from the one for inhalation, because the effective air concentration for inhalation depends on times spent indoors and outdoors.

RESRAD has in common with the other computer programs considered in this report — except MMSOILS — the capability of performing its calculations for radionuclides that belong to possibly long and complex decay chains. This capability involves solving generalizations of the well-known Bateman equations of decay and formation of radioactive progeny, combined with first-order removal of radionuclides and decay products from environmental compartments. Although mathematically routine, the computational details are quite tedious and susceptible to errors from loss of significant digits if the strategy is not carefully managed. For the radionuclides present in the Rocky Flats soils, the decay chains are non-trivial and make ad hoc calculations tedious.

RESRAD also provides virtually exhaustive output, summarizing all input data and database numbers and providing nearly every breakdown of output by pathways, radionuclides, dose, and concentration in media that might be desired.

#### 4.2.2 Code acquisition

Argonne National Laboratory sent us Version 5.82 of RESRAD for Windows October 13, 1998, together with the manual for Version 5.0, with no notification of availability of updated documentation. Our request for the DOS version was declined, in a letter stating that the DOS version was no longer distributed. On October 23, 1998, the Rocky Flats Citizen Advisory Board received the computational part of the source code for Version 5.62, accompanied by a letter to Mr. Tom Marshall, Chairman, from W. Alexander Williams of the DOE Office of Eastern Area Programs, Office of Environmental Restoration, Germantown, MD. In the letter, Dr. Williams states that the computational code for Versions

5.61 and 5.62 is identical. He cautions that Versions 5.61 and 5.62 were written for the DOS operating system and are no longer distributed. Windows versions of RESRAD 5.61 and 5.62, he states, "were available for test and evaluation, [but] these versions may not be compatible with newer releases of the WINDOWS operating system." He alludes to "changes made in RESRAD to accommodate the changing computer platforms." Although the letter emphasizes changes that relate to the compatibility of RESRAD with different versions of the Windows operating system (presumably Windows 3.1 vs. Windows 95/98/NT), it makes no mention of the algorithmic differences between versions 5.62 and later versions beginning with 5.75. As we pointed out in Section 4.2.1, these algorithmic differences affect the resuspension pathway, in particular, and the resulting estimates of dose and soil action levels in potentially significant ways. We were not provided with computational source code for Version 5.75 or later.

We have developed an initial front-end program that performs preliminary calculations related to contemporary levels of plutonium, americium, and their decay products in the soil east of the 903 Pad. This front-end program writes files for RESRAD to read and then initiates the execution of RESRAD. The front-end program can execute RESRAD repeatedly in Monte Carlo fashion to obtain distributions of estimated radionuclide concentrations or annual doses to exposed scenario subjects. This particular front-end program is intended for use with the contemporary (unremediated) levels of radionuclides; variant versions will be prepared that will calculate soil action levels. Such a front-end approach permits us to substitute alternative resuspension mechanisms that RESRAD does not incorporate, as discussed in Section 3.1.3. Details of the front-end programs will be given in the Task 5 report.

If the questions of algorithmic inconsistency between the RESRAD documentation and the program can be resolved satisfactorily, we believe RESRAD can be used as the primary tool for investigating the benchmark (and possibly other) scenarios of use of the Rocky Flats site and the establishment of the relationship between radionuclide levels in the soil and annual dose standards (soil action levels, in particular). Factors that weigh in favor of RESRAD are (1) its continuing support by DOE, (2) its longevity, with a corresponding base of experience and understanding of its strengths and limitations, (3) its extensive well-formatted output, and (4) its design that permits us to separate the calculating engine from its graphic user interface and control it from a front-end scripting program. RESRAD has no monopoly on these features individually, but collectively it achieves a marginal lead over GENII, the other program that was not eliminated from consideration for this project. The inconsistencies in the distributed materials for RESRAD, however, are troubling. The fact that DOE does not choose to make the source code generally available for public inspection is also a negative consideration. If the source code were made available on a web site for downloading, it is our opinion that the useful feedback from a variety of users and programmers would result in developmental improvements and user confidence that would far outweigh whatever concerns the agency might have regarding unauthorized substitutions of code in compliance calculations.

With the reservations noted previously regarding the inter-version changes in mechanical resuspension of contaminated particles, the models offered by RESRAD are generally appropriate for application to the benchmark scenarios defined by the soil action levels document (DOE/EPA/CDPHE 1996) and to others constructed for purposes of

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illustration or likely to be proposed as alternatives to the benchmark set. However, as with any environmental models, they should be applied with a healthy amount of skepticism.

Use of RESRAD should not exclude the use of other similar tools or ad hoc programs when their use is indicated for comparisons needed to shed light on questions of the performance of the environmental models. This choice of a tool should not be allowed to substitute a computer program for the underlying mathematical models and scenario definitions, which are paramount. As our comparison of RESRAD and GENII illustrates (Section 4.4.3), more or less equivalent calculations can be performed with a variety of programs or combinations of programs, provided the mechanisms are understood and differences of implementations are properly allowed for. On the other hand, it is entirely possible to make erroneous calculations with the tool of choice. We must stress the continuing involvement of professional people who have experience with environmental assessments, the relevant models, and the appropriate computing tools. Despite the early expectations of the regulatory agencies, it does not seem possible to package all of this knowledge, once and for all, in a canonical computer program and prescribe its parametric application to all sites and situations without further analysis.

#### 4.2.3. Changes in the area factor for resuspension

We have previously alluded to algorithmic changes in RESRAD, beginning with Version 5.75, that affect the resuspension mechanism. Given the importance of resuspension in the Rocky Flats context, these changes are of potentially substantial significance.

Discussion of these changes and the related mechanisms is of necessity somewhat technical. The changes involve the calculation of the area factor, which affects resuspension predictions. The area factor accounts for the dilution of locally contaminated airborne dust by uncontaminated dust resuspended from outside the contaminated area. Larger (smaller) area factors correspond to larger (smaller) predictions of airborne contamination, which would produce larger (smaller) predictions of dose by inhalation and by external exposure to airborne gamma-emitting radionuclides. Bearing these relationships in mind, some readers may prefer to refer primarily to Figure 4.2.3-1 for a sense of the extent to which the changes might reduce RESRAD predictions of air concentration.

To understand the meaning of an area factor for resuspension, we must consider a process of suspension, balanced by deposition, of uniformly contaminated soil that occurs upwind from a receptor location at which we are interested in the air concentration. If the upwind fetch is infinite, we would anticipate a larger air concentration of radioactivity at the receptor point than would occur if the contaminated region were finite (which is what we are assuming in applications of RESRAD). The strategy in RESRAD is to estimate an air concentration that would correspond to an infinite region and correct it by multiplying it by a factor that represents the ratio of concentration due to the finite area divided by the concentration due to an infinite fetch. A value equal to this ratio must, of course, be derived in a round-about way, because the numerator of the ratio is the very concentration that we are trying to calculate. It is this ratio that is called the *area factor* for resuspension.

Before Version 5.75, RESRAD used an area factor (AF) that can be derived from a simple box model of the resuspension and deposition process (see, for example, Hanna et al. (1983), Chapter 9). If  $\sqrt{A}$  is taken as the linear dimension of the contaminated region in the

direction of the wind, where  $A$  is the area, the ratio defined in the previous paragraph can be shown to be

$$AF = \frac{\sqrt{A}}{\sqrt{A} + DL} \quad (4.2.3-1)$$

where  $DL$  is a dilution length that depends on the deposition velocity, the mean wind speed, and the mixing height (height of the atmospheric layer over which the concentration is averaged). RESRAD generically used a default value of 3 m for the dilution length, although it should be considered a highly variable parameter (3 is the geometric mean of 0.03 and 250 m, corresponding, we are told, to surface roughness and the height of the stable planetary boundary layer, respectively; see Chang et al. (1998)).

In what the developers of RESRAD consider a more refined approach, they have developed an area factor that considers vertical and crosswind diffusion as represented by a Gaussian plume model, with gravitational settling estimated by Stokes's law (using a tilted plume to account for depletion) and wet deposition using a scavenging model. These models introduce additional parameters, such as the size distribution of aerodynamic diameters (1 to 30  $\mu\text{m}$  is the size range considered in studying the variability of the area factor), particle density, rainfall rate, raindrop size, wind speed, and the dispersion coefficients  $\sigma_y$  and  $\sigma_z$  as functions of atmospheric stability and distance from the source. The point source of the Gaussian plume is integrated over the finite contaminated area, while the receptor is kept fixed at the midpoint of the downwind boundary. The corresponding concentration for an infinite area is obtained by increasing the area of the square source region until the receptor concentration converges to a maximum value.

Reference values are assumed for some of the parameters, namely rainfall rate (100  $\text{cm year}^{-1}$ ), particle density ( $2.65 \text{ g cm}^{-3}$ ), atmospheric stability (Pasquill-Gifford class D, which typically occurs almost half of the time), and raindrop diameter (1 mm). The model is represented by a logistic regression curve, which was fitted to data generated by calculations for a grid of points in the parameter space. The function is

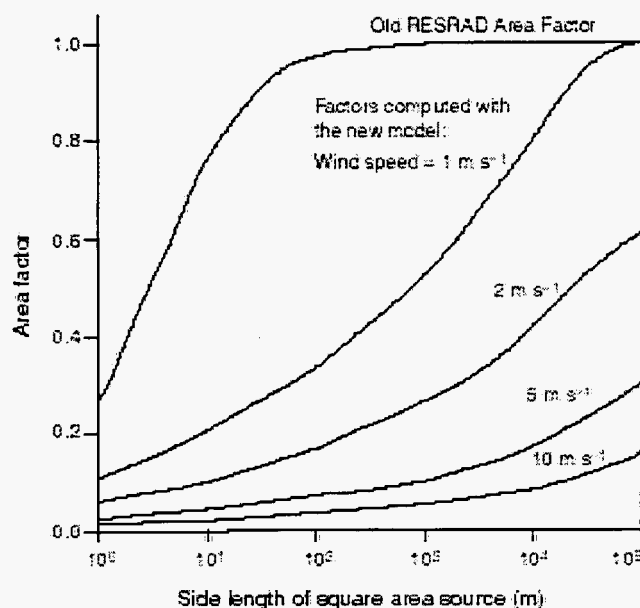
$$AF = \frac{a}{1 + b(\sqrt{A})^c} \quad (4.2.3-2)$$

where  $A$  is the area of the contaminated zone and each of the parameters  $a$ ,  $b$ , and  $c$  is a function of the particle diameter ( $\mu\text{m}$ ) and wind speed ( $\text{m s}^{-1}$ ). The functional correspondence for  $a$ ,  $b$ , and  $c$  is shown in Table 4 of Chang et al. (1998).

Wind speed is available as an input to RESRAD, but particle aerodynamic diameter is not. The dose conversion factors for inhalation in the RESRAD database are based on activity median aerodynamic diameter 1  $\mu\text{m}$ , and the RESRAD developers have chosen to fix the particle size parameter at this value for the present. Chang et al. (1998) compare the old and new area factors (Equations 4.2.3-1 and 4.2.3-2, respectively) in a series of plots in their Figure 5, for values of the particle diameter ranging from 1  $\mu\text{m}$  to 30  $\mu\text{m}$ . Using the plot corresponding to 1  $\mu\text{m}$  and the curve for wind speed =  $5 \text{ m s}^{-1}$  (the average for the Denver area is about  $4 \text{ m s}^{-1}$ ), with a contaminated area of  $10^4 \text{ m}^2$ , the old factor exceeds the new by roughly a factor of 6; for  $100 \text{ m}^2$ , the old area factor is more than 10 times the new one. Lower wind speeds correspond to lesser discrepancies, and higher wind speeds would give larger ones. Larger areas would correspond to better agreement between the two area factors.

Figure 4.2.3-1 shows a comparison of the old and new area factors for particle diameter  $1\ \mu\text{m}$  plotted against  $\sqrt{A}$  for several values of the wind speed.

In reading the documentation of Chang et al. (1998), we could not be certain that the distinction between physical and aerodynamic particle diameters was being consistently observed. In the form of Stokes's law that is quoted, the physical diameter is the correct interpretation. But if the tabulations are then based on physical particle diameters, a physical diameter of  $1\ \mu\text{m}$  would not correspond to an activity median aerodynamic diameter of the same numeric value, but rather to a median diameter of about  $\sqrt{2.65} \approx 1.6$  (given the assumed density of the particles). The language should be clarified.



**Figure 4.2.3-1.** Comparison of the old and new RESRAD area factors for particle size  $1\ \mu\text{m}$ , plotted against the side length of a square contaminated area. The new area factor is shown for several values of the wind speed. This figure was redrawn from Chang et al. (1998).

A potentially more serious criticism concerns the generic use of this area factor in assessments at various locations with different circumstances. Perhaps in anticipation of this point, Chang et al. (1998) present a series of sensitivity calculations, varying pairs of parameters, and showing results separately for particle diameters 1, 10, and  $30\ \mu\text{m}$ . The variable pairs are wind speed and rainfall rate; wind speed and particle density; and wind speed and atmospheric stability. In each case, the relative area factor (perturbed divided by nominal) is plotted against the side length of the area source. The greatest variations from the nominal case occur for variations involving particle density (from 1.325 to 5.0  $\text{g cm}^{-3}$ ) and for high wind speeds in unstable air. Most variations of the relative area factor are within a factor of two, and none is as large as a factor of three.

The presentation of this sensitivity analysis may tempt a reader to the conclusion that the uncertainty introduced into resuspension-dependent quantities by the area factor is some composite of the variability shown in the figures. However, the sensitivity analysis

demonstrates only the propagation of parameter variations; it does not necessarily deal with uncertainty in the models themselves relative to the real environment. For example, Miller and Hively (1987) reviewed numerous applications of the Gaussian plume model to cases where such variables as the release rate, wind speed, atmospheric stability, and downwind concentrations were monitored or could be considered known. At best, the predicted annual-average concentrations agreed with the observations to within a factor of two when the terrain was regular and the meteorology unexceptional (i.e.,  $0.5 \leq \text{predicted} / \text{observed} \leq 2$ ); in cases of irregular terrain or (for example) coastal meteorology, the reported annual-average uncertainty was a factor of ten. Generic application of a Gaussian plume model should involve consideration of these uncertainties. Of course, the application of the Gaussian plume to the area factor differs in scale and detail from conventional predictions of concentration downwind from a source, and in some part the uncertainty may derive from parametric uncertainties, but it seems to us that we cannot assume *a priori* that the model is intrinsically more reliable for deriving the area factor than the study of Miller and Hively (1987) has shown it to be for conventional applications.

Another point that can be raised regarding the models used to derive the area factor is that the representation of dry deposition by the Stokes's-law gravitational settling model is at best an approximation that ignores the partial dependence of the particle behavior on micrometeorological variables. For particles with aerodynamic diameter near  $1 \mu\text{m}$ , Stokes's law may not be an adequate parameter for total deposition for purposes of the area factor.

It is not our intent to criticize the RESRAD developers. The models and parameters that they have applied to estimate the area factor are well known and frequently invoked. Their approach is rational from a research standpoint, their analysis seems thorough, and we are appreciative of the well-organized numerical explorations they have provided in Chang et al. (1998). Our reservations have more to do with objections to generic application of assessment models. The developers consider this formulation of the area factor more realistic than the older version that was based on a simple box model (Equation 4.2.3-1), and that may be true. But in any assessment, the analyst should be weighing the appropriateness of any factor that enters into the calculations for the site in question and integrating each factor into the composite uncertainty picture. We certainly agree with the last sentence in Chang et al. (1998): "However, if measurement data are available, the measured air concentrations [*sic*] data should be used in RESRAD analysis." The user's manual should clarify just how this is to be done; we assume it would involve supplementary off-line calculations based on RESRAD output. We will be making use of such measurements in the calculations for Task 5.

In general, one can expect Versions 5.75 and newer of RESRAD to predict lower annual resuspension-dependent doses and correspondingly larger radionuclide soil action levels, with the extent of the discrepancy depending on the values supplied for the mean wind speed and the area of the contaminated zone. For application to the Rocky Flats site, we cannot make a more definite statement at this time, until an appropriate area for the field of contamination is determined. In regard to the version of RESRAD that will be applied, there is some ambiguity about the intentions of the regulatory agencies. The soil action level document (DOE/EPA/CDPHE 1996) presents RESRAD parameters and computed soil action levels that appear to correspond to an earlier version of the code (perhaps 5.61 or 5.62). This was probably the most recent version available at the time that document was prepared. But if the assessment were to be carried out in a purely formal manner, with the newer

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version of the code being substituted and executed with the same set of parameters, the foregoing analysis indicates that a possibly important change in the predictions would occur.

#### 4.3 MEPAS

The Multimedia Environmental Pollutant Assessment System (MEPAS) was developed at Pacific Northwest Laboratory under DOE sponsorship. Offered as a commercial product by Battelle Memorial Institute under a technology-transfer agreement with DOE, MEPAS is the most ambitious of the programs considered here. It advertises applicability to both chemical and radioactive pollutants, with computation of human health risk for carcinogens and hazard quotients (sometimes called hazard indices) for noncarcinogens. MEPAS includes air transport models in addition to surface water and groundwater transport, and it treats all major exposure pathways (Buck et al. 1995). As we mentioned in Section 3.1.3, MEPAS incorporates variants of the EPA models for particulate suspension by mechanical and wind-driven erosion (Battelle Memorial Institute 1997). The MEPAS documentation that we have reviewed does not indicate an intrinsic Monte Carlo capability for uncertainty analysis.

Battelle Memorial Institute declined our request for permission to examine portions of the MEPAS source code. Absent special instructions, such access would be necessary to allow us to discover how to circumvent the graphic user interface and prepare a front-end interface program to provide Monte Carlo simulations and initial calculations. Accordingly, we cannot give further consideration to MEPAS at this time for application to the Rocky Flats site soil contamination. This decision was taken for reasons of practical necessity; it does not deny the potential applicability of the MEPAS models to the problems we are considering. However, it is not clear that MEPAS would offer any decided advantage over RESRAD or GENII for the specific calculations that we are considering. The wealth of models and options that MEPAS offers would likely be wasted, for the most part.

Considerable effort has gone into benchmarking MEPAS with RESRAD and MMSOILS (Laniak et al. 1997; Mills et al. 1997). In response to our request for source code access, we were sent the report of Cheng et al. (1995), which presumably is a more detailed account of the work reported by Laniak et al. (1997) and Mills et al. (1997), and what appears to be a prepublication copy of a report without a cover page, with the title *Test Plan and Baseline Testing Results for the MEPAS Saturated Zone (Aquifer) Transport Model*. These reports did not reach us in time to permit a proper examination of them, and we do not comment further on them at this time.

#### 4.4 GENII

At the direction of the U.S. Department of Energy in 1988, the Hanford Environmental Dosimetry Upgrade Project was undertaken by Pacific Northwest Laboratory to incorporate the internal dosimetry models recommended by the International Commission on Radiological Protection into updated versions of the environmental pathways models used at Hanford. The resulting second generation environmental dosimetry computer codes were compiled in the Hanford Environmental Dosimetry System — Generation II or GENII (Napier et al., 1988). The GENII system was developed by means of tasks designed to provide a state-of-the-art, technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment.

#### 4.4.1 Code overview

The GENII system was designed to address exposure and dose resulting from both routine and accidental releases of radionuclides. Doses may be calculated on an annual, committed, or accumulated basis. Transport pathways include air, soil, biotic, surface water, and to a limited extent, drinking water. Pathways of exposure include direct or external exposure via water (swimming, boating, and fishing), soil (surface and buried sources), and air (semi-infinite and finite infinite cloud geometries), inhalation pathways, and ingestion pathways. The inhalation pathway includes direct inhalation of material released to the air from a facility or operation, and inhalation of resuspended contamination from the soil. Ingestion pathways include soil, and transfer of radioactivity from soil to food products (produce, milk, meat, and poultry), and contaminated drinking water.

GENII includes options for calculating both near-field and far-field (some refer to near-field as onsite and far-field as offsite) exposure scenarios. In a near-field scenario, the focus is on the doses an individual could receive at a particular location as a result of initial contamination or external sources at that location. A far-field scenario considers the doses received by an individual or a population exposed to radioactivity that has been released and transported from a location remote from the receptor. The two types of scenarios are not mutually exclusive, and any given scenario may have components of both the near- and far-field scenarios.

The proposed soil action levels developed for the RFETS are essentially based on a near-field scenario. The RESRAD code is not capable of addressing directly what GENII defines as a far-field scenario, and therefore, GENII appears to have an advantage as a model that may provide dose estimates to off-site individuals. Far-field scenarios in GENII include chronic and acute atmospheric releases, and chronic and acute surface water releases. Doses from ingestion of contaminated groundwater may be calculated in GENII, but groundwater concentrations must be computed externally to the code, using a model suited to that type of computation or direct measurements.

Source term input to GENII may be in the form of effluent release rates to various environmental media (air, soil, or water), or initial contamination levels in these media. The code allows for environmental transport calculations to be performed externally to GENII and the results input by way of a dispersion factor or a user-defined concentration value in an environmental medium. Radioactive decay and formation of decay products are handled within the code. Half-lives, dose conversion factors, and animal and plant uptake factors are stored for a library of 251 nuclides. In addition, the decay chain is automatically constructed once a parent nuclide is selected, and decay and formation of progeny are calculated for the entire decay chain over time.

The GENII package of codes was developed under a stringent QA plan based on the American National Standards Institute (ANSI) standard NQA-1 (ASME 1986) as implemented in the PNL Quality Assurance Manual PNL-MA-70<sup>1</sup>. All steps of the code development have been documented and tested. Extensive hand calculations have been performed and are available for review on request

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<sup>1</sup> Procedures for Quality Assurance Program, PNL-MA-70. This is a controlled document used internally at PNL. Information regarding the manual may be obtained from Pacific Northwest Laboratories, Richland, Washington.

#### 4.4.2 Code features relevant to calculating soil action levels for Rocky Flats

GENII models the same pathways that are included in the RESRAD simulations that were used in the soil action levels document (DOE/EPA/CDPHE 1966). These pathways are resuspension and inhalation of contaminated soil, inadvertent soil ingestion, transfer of radioactivity into homegrown produce and animal products, and external exposure of the subject to surface soil contamination and contaminated airborne particles. Two resuspension models are available in GENII: a mass loading approach that is similar to the one in RESRAD Versions prior to 5.75, and a time-dependent method developed by Anspaugh et al. (1975). The Anspaugh model was calibrated to empirical data that showed a decrease in the amount of resuspended material over time. It appears that the Anspaugh model is not applicable to the Rocky Flats environs because it applies only to the first 17 years following a deposition event. In the case of the soil at Rocky Flats, the contamination has been there for more than 30 years.

External exposure in GENII is calculated using a modified version of the ISOSHIELD code (Engel et al. 1966). The ISOSHIELD code uses the commonly accepted techniques of Rockwell (1956) or other standard references for computing exposure rates from isotopes distributed in various geometric configurations. The calculation considers the initial photon, energy spectrum, material properties in the source region, air, and any shielding materials placed between the source and receptor (such as a cover layer of soil), and mass attenuation and build-up within the source and shield materials. Exposure rates (in Roentgen per hour) are converted to effective dose equivalents using the energy-dependent surface-dose to organ-dose conversion factors derived from information in Kocher (1981). Organ weighting factors were obtained from ICRP 26 (ICRP 1977).

Two models are available for ingestion of contaminated crops. These models are a chronic exposure model and an acute exposure model. The chronic exposure model assumes a constant source of contamination released to the model domain. The acute model assumes an initial contamination level in soil and water that is not replenished over time. The acute model appears to be appropriate for the Rocky Flats site, because the site will be shut down and release no additional radioactivity (other than what is currently present) to the environment. The acute model of GENII is conceptually similar to the PATHWAY model (Whicker and Kirchner 1987) but uses fewer inputs. It includes the processes of root uptake, recycling of contamination on the plant surface with the surface soil, redistribution due to tilling, and translocation of contamination from non-edible to the edible portions of the plant. GENII also includes models for calculating transfer of radioactivity from the soil to animals and animal products, such as milk meat, eggs, and poultry. These pathways were not considered in the original conceptual model defined for the proposed soil action levels, but it is conceivable that alternative scenarios might include them.

GENII also considers an on-site groundwater pathway like RESRAD. However, RESRAD computes transport from the source, through the vadose (unsaturated) zone, and into the aquifer while GENII only allows the user to input a previously measured or modeled groundwater concentration, and dose calculations are performed on that basis. In RESRAD, the groundwater model consists of relatively simple representations of subsurface aqueous flow and transport and does not consider off-site transport of contamination in the aquifer.

The internal dose conversion factors provided in GENII are calculated based on the models for dosimetry reported in ICRP Publication 30 (ICRP 1979–1982). These models for

dosimetry were coded into the INTDF code to allow for dose to be calculated on an annual (as opposed to committed) basis for different commitment periods. While this is an important feature of the GENII code, the need to calculate dose at this level of detail is not necessary for meeting the dose requirements for soil action levels. The annual dose limit specified for the soil action levels includes the 1-year effective dose equivalent from external radiation sources and the 50-year committed effective dose equivalent from one year's exposure to internal (inhalation and ingestion) sources. Therefore, only the dose conversion factors representing the 50-year committed dose equivalent are needed for this calculation.

#### 4.4.3 Code acquisition and testing

The GENII computed dose system and documentation, version 1.485 was obtained from the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory. The code was written in FORTRAN, and source code was provided in the distribution. The code was installed on a personnel computer running under Windows 95® and MS DOS® version 6. Primary input to the GENII software package is through an ASCII input file that may be prepared using a menu-driven pre-processor written in BASIC called APPRENTI. Other files containing dose conversion factors, environmental transport factors, and default parameter values are required for execution and are stored in the GENII default subdirectory. These files may be modified by the user using a standard ASCII text editor.

In order to test the code and observe its performance, we set up a GENII simulation assuming the same conceptual model that was used to define the proposed soil action levels for the resident exposure scenario at the Rocky Flats site (DOE/EPA/CDPHE 1996). These results could then be compared to the RESRAD Version 5.61 results, permitting us to highlight differences in the transport, exposure and dosimetry models used between the two codes. Key input parameters applicable to both codes are described in Table 4.4.3-1. Dose conversion factors used in GENII assumed the same lung clearance class and gut absorption fraction as in the RESRAD simulations used to develop the soil action levels reported in DOE (1996). This required several GENII simulations, because in any given GENII simulation, all radionuclides are assumed to have the same lung clearance class and gut solubility. Plant-to-soil concentration ratios were left at their respective default values for each code. Results were normalized to their dose per unit concentration in surface soil (mrem (pCi g<sup>-1</sup>)<sup>-1</sup>) or their dose-to-soil ratio (DSR) for ease of comparison.

**Table 4.4.3-1. Key Input Parameters for the Proposed SAL Conceptual Site Model<sup>a</sup>**

Parameter	Value	Units
Area of contamination <sup>b</sup>	>1250	m <sup>2</sup>
Thickness of contaminated zone	0.15	m
Density of contaminated zone	1.8	g cm <sup>-3</sup>
Time of assessment (time after institutional control)	0	years
Inhalation rate	7000	m <sup>3</sup> y <sup>-1</sup>
Mass loading factor	$2.65 \times 10^{-4}$	g m <sup>-3</sup>
External gamma shielding factor	0.8	---
Fruits, nonleafy vegetables & grain consumption	40.1	kg y <sup>-1</sup>
Leafy vegetable consumption	2.6	kg y <sup>-1</sup>
Soil ingestion rate	70	g y <sup>-1</sup>
Lung clearance class for americium	W	---
Lung clearance class for plutonium and uranium isotopes	Y	---
Gut absorption fraction, plutonium isotopes	$1.0 \times 10^{-5}$	---
Gut absorption fraction, americium isotopes	$1.0 \times 10^{-3}$	---
Gut absorption fraction, uranium isotopes	$5.0 \times 10^{-2}$	---
Mass loading for foliar deposition	$1.0 \times 10^{-4}$	g m <sup>-3</sup>

<sup>a</sup>. from DOE (1996), Attachment I

<sup>b</sup>. Area of contamination in GENII is only defined in terms of less than or greater than 1250 m<sup>2</sup>

The results (Tables 4.4.3-2 and 4.4.3-3) indicate that there is not much difference between the *DSRs* calculated with the two codes for the inhalation and ingestion pathways. However, significant differences were noted for the external exposure pathway and in particular, for <sup>238</sup>U and <sup>241</sup>Pu. The *DSRs* for these two nuclides were significantly smaller for the GENII simulations compared to those of RESRAD Version 5.61. It is not clear whether these differences were due to the photon transport and attenuation models employed in the codes or the methodology to convert exposure rate to effective dose equivalent. Differences as high as 12.4% were also noted in the ingestion pathway for uranium and americium isotopes. These differences may be attributed to differences in the terrestrial food chain models and perhaps to a smaller extent to the dose conversion factors used. The inhalation pathway showed the least amount of difference between the *DSRs* calculated with the two codes. The maximum difference between GENII and RESRAD *DSRs* was 2.9% for <sup>242</sup>Pu. Because both codes use virtually identical resuspension models that make use of the mass loading factor, the difference between the two results can mostly be attributed to their respective dose conversion factors. In terms of the *DSR* for all pathways of exposure (external, inhalation, and ingestion), differences >5% were noted only for the uranium isotopes. For the most part, RESRAD provided a more conservative estimate of dose, except for <sup>241</sup>Am and <sup>234</sup>U, where GENII ingestion doses were higher compared to those calculated by RESRAD. In general, inhalation was the dominant pathway; however ingestion was equally important for the uranium isotopes. According to RESRAD Version 5.61, external exposure was the most important pathway for <sup>238</sup>U.

**Table 4.4.3-2. Dose-to-Soil Ratios (DSR, mrem (pCi g<sup>-1</sup>)<sup>-1</sup>) for RESRAD V. 5.61 and GENII**

Radio-nuclide	RESRAD				GENII Results			
	External	Inhalatio n	Ingestion	Total	External	Inhalatio n	Ingestion	Total
Am-241	.0344	.0811	.282	.397	.0230	.0800	.310	.413
Pu-238	.00012	.0526	.00384	.0566	.00010	.0520	.00370	.0558
Pu-239	.00023	.0563	.00401	.0605	.00022	.0550	.00380	.0590
Pu-240	.00012	.0563	.00401	.0604	.00010	.0550	.00380	.0589
Pu-241	.00001	.00091	.00006	.00098	2×10 <sup>-10</sup>	.00089	.00006	.00095
Pu-242	.00010	.0536	.00381	.0575	.00008	.0520	.00360	.0557
U-234	.00032	.0241	.0249	.0493	.00030	.0240	.0280	.0523
U-235	.583	.0225	.0235	.629	.390	.0220	.0260	.438
U-238	.100	.0216	.0237	.145	.00014	.0210	.0260	.0471

**Table 4.4.3-3. Percent Difference<sup>a</sup> Between the DSRs for RESRAD V. 5.61 and GENII**

Radionuclide	External	Inhalation	Ingestion	Total
Am-241	33.10%	1.40%	-10.06%	-3.98%
Pu-238	16.67%	1.20%	3.60%	1.39%
Pu-239	3.51%	2.29%	5.20%	2.49%
Pu-240	14.38%	2.29%	5.20%	2.51%
Pu-241	100.00%	1.82%	7.20%	3.62%
Pu-242	17.32%	2.89%	5.44%	3.09%
U-234	4.76%	0.50%	-12.39%	-5.98%
U-235	33.07%	2.14%	-10.61%	30.33%
U-238	99.86%	2.64%	-9.79%	67.57%

a. [(DSR (RESRAD) – DSR (GENII))/DSR (RESRAD)]

## 4.5 MMSOILS

Developed for screening analysis of hazardous waste sites, MMSOILS was developed by the EPA's Office of Research and Development, National Exposure Research Laboratory, Ecosystems Research Division, Regulatory Support Branch and is currently available from EPA's web site in Version 4.0. Written in FORTRAN-77 and distributed with full source code and documentation, the MMSOILS program may be implemented under Windows or Unix operating systems. The accompanying documentation, which includes a user's guide and descriptions of the models, is detailed and extensive (EPA 1996).

The MMSOILS goal is estimation of human exposure and health risk from chemically contaminated hazardous waste sites. Collectively, the models of MMSOILS provide a multimedia tool that simulates chemical transport in the atmosphere, soil, surface water, groundwater, and the food chain. It treats inhalation of airborne volatile and particulate materials, drinking contaminated water, ingestion of soil, and consumption of crops and animal products that were produced on contaminated land. The program includes a Monte

Carlo mechanism for propagating parameter uncertainties into estimates of exposure and risk. MMSOILS has been benchmarked with RESRAD and MEPAS (Laniak et al. 1997; Mills et al. 1997).

It is possible to apply MMSOILS to radionuclides in the soil, but the program has no mechanism, beyond simple radioactive decay, for dealing with decay chains. Allowing for the possibility that we might be able to simulate this mechanism by pre- and post-processing methods, we included MMSOILS in the list of programs to be considered. But as a practical matter, given the time constraints of this project, such an approach would not be satisfactory. In these circumstances, we must rule out the use of MMSOILS for estimating dose and developing soil action levels for the Rocky Flats site.

#### 4.6 DandD

The software package *Decontamination and Decommissioning* (DandD) was designed by the U.S. Nuclear Regulatory Commission (NRC) as a user-friendly analysis tool for NRC rulemakers and facilities under NRC regulation seeking decommissioned status. The code incorporates the information contained in NUREG/CR-5512, Volume 1, and helps NRC licensed facilities determine the level of cleanup required to allow the release of their property for unrestricted use.

##### 4.6.1. Code overview

DandD was designed as a screening level analysis program to provide a simplified estimate of the dose to an average member of a carefully specified critical screening group (Daily 1999). The estimate is designed to be "prudently conservative" but is not designed to be used as an estimate of actual dose (NRC 1992).

The DandD code includes four exposure scenarios: building renovation, building occupancy, drinking water, and residential. For the residential scenario, the pathways included are external exposure, inhalation, drinking water ingestion, ingestion of food grown from irrigated water, land-based food ingestion, soil ingestion, and fish ingestion. The pathways are hard-wired into the scenarios and can only be removed from consideration by zeroing the annual intake of any given product.

Input parameters for each of the DandD scenarios have default values that were selected in such a way as to be "prudently conservative" (NRC 1992). The default values were chosen for a select and limited population group, and are not intended to represent the average over an entire population. DandD does allow modification of each parameter value within a limited range. Parameter values that are outside the range of allowed values are not accepted as input to the code. These ranges were selected using an analysis done by Sandia National Laboratory in 1997 and 1998. NRC warns that use of this conservative generic approach requires a great deal of professional judgment and common sense (NRC 1992). The intent of the code is to account for the majority of potential land and structural uses, and the code is designed to overestimate the most probable annual dose.

Doses calculated with DandD are total effective dose equivalent (TEDE) estimates, which include annual effective dose and committed dose equivalent during each year. The dose reported in the output of the calculation is the committed dose for the year of maximum total committed dose. This is comparable to the dose limit input in RESRAD (e.g. for the Rocky Flats calculation, 15 or 85 mrem according to the scenario being considered).

Source term input to DandD is strictly in the form of initial concentrations of radionuclides in soil. Radioactive decay and progeny ingrowth are calculated within the code. Half-lives, dose conversion factors, and organ specific dose conversion factors are not available as inputs within the code and remain fixed throughout the calculations. In keeping with the "prudently conservative" goal of the code, the chemical form of the radioactive material that would confer the largest dose is assumed to exist in all cases. For plutonium, this means that the most soluble form of plutonium is assumed, and the dose conversion factors used by DandD correspond to this form (clearance class W for inhalation and  $f_1 = 10^{-3}$ ).

It is important to point out that DandD is in Version 1.0 and has not yet undergone extensive scrutiny or use. Documentation that accompanies the code has not been published, nor has the source code been publicly released. This makes it difficult to use the code and even more difficult to make confident statements about how the code functions. The release of this documentation is not scheduled to occur within a time that would allow consideration of DandD for use in this project. RAC has requested and awaits receipt of all code documentation and source code material upon its publication.

We have gone forward with our analysis of this code in a limited fashion to show some of the limitations of the code in its present form for application to this project.

#### **4.6.2. Code features relevant to calculating soil action levels for Rocky Flats**

DandD models most of the same pathways as RESRAD, but some of the details about the pathway analyses have been difficult to determine without supporting documentation.

Resuspension and inhalation of contaminated soil are modeled in DandD using a mass loading model that appears to be similar to the one in RESRAD Versions earlier than 5.75, but using an additional level of detail. DandD partitions residential scenario annual activity into three different categories that are accompanied by three different mass loading factors and three different breathing rates. The three categories are indoor, outdoor, and outdoor gardening. We do not have information about how area factors are handled.

The contamination of vegetables, fruits, and roots is represented by two mechanisms: foliar mass loading of resuspended soil and root uptake of contaminated soil. The most significant difference between the way RESRAD and DandD model contamination of food products from contaminated soil has to do with the soil to plant resuspension and deposition pathway.

DandD assumes a constant ratio between radionuclide concentrations in plants and soil, using a default mass loading value of  $0.1 \text{ pCi g}^{-1}$  dry plant per  $\text{pCi g}^{-1}$  dry soil. This parameter value means that plant foods are assumed to be 10% soil by weight, a rather high estimate. DandD further applies a translocation fraction of 1.0 for contamination deposited on leafy vegetables, which means that all of the soil deposited on the leaves is integrated into the edible portions of the plant.

The RESRAD model assumes a constant deposition rate with removal controlled by a first-order weathering constant (NRC 1998). The deposition and removal are assumed to occur over the entire growing season. For radionuclides without a high degree of root uptake, like plutonium, the mass loading factor in DandD dominates the ingestion dose and the total dose for the year of maximum dose. This factor seems to be controlling the dose from

radionuclides without a high degree of root uptake and causing doses calculated with DandD to be higher than those calculated with RESRAD.

#### 4.6.3. Code acquisition and testing

The DandD Version 1.0 windows-based executable file was downloaded from the NRC web site. Supporting documentation has been requested from NRC but not yet received. The code was written in the FORTRAN programming language, and RAC expects to receive the source code upon its release for public distribution later this month. Input to the DandD code is provided by the user through a graphic user interface.

To test and observe the performance of the DandD code, we attempted to reproduce the hypothetical residential scenario used at Rocky Flats to calculate soil action levels (DOE 1996). This was somewhat difficult to do, as a result of the variant definitions of inputs between the two codes and the fact that some parameters used in the Rocky Flats analysis were outside the allowed distributions of parameter values in DandD or were treated as constants by DandD and could not be altered. The difference between the results are highlighted below, but the reasons are not always known, since the documentation has not yet been published and the models are not transparent.

Table 4.6.3-1 shows some of the key parameters used in each calculation. Since the DandD code uses Class W (soluble) plutonium for inhalation and a gut adsorption fraction for ingestion of  $10^{-3}$ , the Rocky Flats RESRAD calculation was changed so that solubility class matched the DandD values (RESRAD Version 5.61 was used). This was the only change necessary to make in the Rocky Flats calculation. All further changes were made to the DandD input parameters.

Because it is not possible to inactivate pathways in DandD the way it is in RESRAD, a number of parameters were set to zero to simulate this. To match the DOE Rocky Flats RESRAD calculation, the parameters that control the pathways for meat, milk, poultry, and aquatic food ingestion, as well as the ground and surface water pathway, were set to zero.

**Table 4.6.3-1. Key Input Parameters for the RESRAD V 6.1 to DandD Comparison**

Parameter	RESRAD value	DandD value
Thickness of contaminated zone	0.15 m	0.15 m
Density of contaminated zone	1.8 g cm <sup>-3</sup>	1.8 g cm <sup>-3</sup>
Time of assessment (after shut down)	0	0
Inhalation rate	7000 m <sup>3</sup> y <sup>-1</sup>	0.8 m <sup>3</sup> h <sup>-1a</sup>
Mass loading factor for inhalation	2.65 x 10 <sup>-5</sup> g m <sup>-3</sup>	2.65 x 10 <sup>-5</sup> g m <sup>-3</sup>
Fruit, nonleafy vegetables & grain consumption	40.1 kg y <sup>-1</sup>	40.1 kg y <sup>-1</sup>
Leafy vegetable consumption	2.6 kg y <sup>-1</sup>	2.6 kg y <sup>-1</sup>
Soil ingestion rate	70 g y <sup>-1</sup>	0.095 g day <sup>-1b</sup>
Lung clearance class, americium	W	W
Lung clearance class, plutonium isotopes	W	W
Lung clearance class, uranium isotopes	Y	Y
Gut adsorption fraction, americium	1.0 x 10 <sup>-3</sup>	1.0 x 10 <sup>-3</sup>
Gut adsorption fraction, plutonium isotopes	1.0 x 10 <sup>-3</sup>	1.0 x 10 <sup>-3</sup>
Gut adsorption fraction, uranium isotopes	5.0 x 10 <sup>-2</sup>	5.0 x 10 <sup>-2</sup>

<sup>a</sup>DandD input units shown; this converts to the same value as the RESRAD parameter.

<sup>b</sup>DandD input units shown; this converts to half the RESRAD parameter, but DandD parameter distributions would not allow the RESRAD value, so the calculation was run with this input and soil ingestion dose from DandD was multiplied by 2.

An important parameter that could not be reconciled between the two codes is the mass loading for foliar deposition. As described above, the pathway for contamination of plants from resuspension of contaminated soil is quite different between the two models. In creating dose to soil concentration ratios for RESRAD and DandD for Table 4.6.3-2, the DandD code was run twice for each radionuclide using the above parameters. In the second run, the value for the foliar mass loading was reduced from the default value by a factor of 10 to display the large effect that this parameter has on the outcome of the calculation. Foliar mass loading in DandD is in units of picocuries per gram of dry plant matter per picocurie per gram of dry soil. The impact of this change on the dose to soil concentration ratio is shown in Table 4.6.3-2. Even with the factor of 10 reduction, the total dose to soil concentration ratios are still significantly higher for DandD than RESRAD. Table 4.6.3-3 shows the percent difference between the dose to soil concentration ratio for RESRAD and DandD.

Without the appropriate documentation, it is not possible for us to acquire a proper understanding of the models and parameters employed in DandD. This lack of available documentation precludes further consideration of DandD in this analysis.

**Table 4.6.3-2. Dose-to-Soil Concentration Ratios (DSR, mrem (pCi g<sup>-1</sup>)<sup>-1</sup>) for RESRAD and DandD**

RESRAD						
Radionuclide	External Inhalation	Inhalation	Plant ingestion		Soil ingestion	Total
Am-241	.0344	.0796	.0269		.255	.396
Pu-238	.00012	.0703	.0237		.224	.318
Pu-239	.00023	.0769	.0262		.248	.351
Pu-240	.00012	.0769	.0262		.248	.351
Pu-241	.00001	.00148	.00051		.0048	.0068
Pu-242	.00010	.0737	.0249		.235	.334
U-234	.00032	.0237	.0051		.0198	.0489
U-235	.583	.0221	.0048		.0187	.628
U-238	.100	.0212	.0049		.0188	.145
DandD						
Radionuclide	External Inhalation	Inhalation	Plant ingestion (ML = 0.1)	Plant ingestion (ML = 0.01)	Soil ingestion	Total (ML = 0.01)
Am-241	.0443	.147	4.3	.445	.252	.89
Pu-238	.00015	.13	3.75	.37	.222	.73

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Pu-239	.00029	.142	4.17	.419	.246	.81
Pu-240	.00029	.142	4.17	.419	.246	.81
Pu-241	.00005	.00279	.0829	.00834	.00484	.016
Pu-242	.00013	.136	3.96	.398	.232	.77
U-234	.00041	.0439	.347	.0472	.0297	.11
U-235	.748	.0407	.328	.0445	.0186	.85
U-238	.11	.0393	.329	.0446	.0185	.22

**Table 4.6.3-3. Percent Difference<sup>a</sup> Between the DSRs for RESRAD and DandD**

Radionuclide	External	Inhalation	Plant ingestion (ML=0.1)	Plant ingestion (ML=0.01)	Soil ingestion	Total (ML=0.01)
Am-241	-28.8%	-84.7%	-15800%	-1550%	1.18%	-125%
Pu-238	-26.7%	-84.9%	-15800%	-1490%	0.89%	-129%
Pu-239	-20.6%	-84.7%	-15800%	-1490%	0.81%	-131%
Pu-240	-145%	-84.7%	-15800%	-1490%	0.81%	-131%
Pu-241	-263%	-88.5%	-15800%	-1490%	-1.04%	-136%
Pu-242	-27.5%	-84.5%	-15800%	-1490%	1.28%	-131%
U-234	-28.9%	-85.2%	-6690%	-824%	0.51%	-125%
U-235	-28.3%	-84.2%	-6690%	-821%	0.54%	-35.4%
U-238	-13.0%	-84.9%	-6690%	-818%	1.59%	-51.7%

<sup>a</sup>[DSR(RESRAD) - DSR(DandD)] / DSR(RESRAD)



## 5. CONCLUSIONS AND RECOMMENDATIONS

It seems clear from the tests and comparisons reported in Section 4 that either RESRAD or GENII could be adapted for purposes of the project. Because of its earlier stage of development and still limited documentation, DandD cannot be counted on in the time available for this project. In addition, the strong orientation of DandD to screening calculations would make it less suitable for the kind of assessment that is envisioned for Rocky Flats. MEPAS and MMSOILS were ruled out on other practical grounds.

RESRAD and GENII are based on similar models, for the most part, and the agreement of their results for the same scenario is not really surprising. The change in the RESRAD area factor for resuspension beginning with Version 5.75 is a complication. We have confined our comparisons to pre-5.75 versions of RESRAD. It is possible to circumvent the resuspension area factor with the earlier versions of RESRAD, thereby permitting the substitution of other resuspension models, but this may be more complicated with the new algorithm.

We want to emphasize one last time that none of these computer programs can guarantee the "right answer." It could be argued that there is no such thing. These programs are tools, which, in the hands of careful analysts, can be useful for carrying out the relevant computations for an assessment, or when used in the absence of proper analysis can produce misleading information. It now appears that either RESRAD or GENII applied with experience, skill, careful consideration of site conditions and data, and with proper interpretation and communication of the results, can help to complete a persuasive assessment of the RFETS. Analysts will have to make adjustments for the differences in the two programs, but used properly, they should lead to similar results. RESRAD provides a more complete listing of database quantities in its output, and some of its defaults regarding inhalation solubility classes and gut absorption factors for the radionuclides considered in a run are more easily changed by the operator. For the assessment at hand, it seems fair to say that RESRAD is the more convenient tool, but GENII may have conceptual or operational advantages in other situations.

When RESRAD is applied to the resuspension pathway, we recommend that it be with full awareness of the effect of the area factor. As we mentioned in Section 3.1.3, measured air concentrations of some of the radionuclides in the source term are available, and careful consideration should be given to using these measurements or calibrating the model to them. This approach may require manipulating the input parameters so that the area factor is effectively 1. Similar manipulations will be required if alternative resuspension models are to be substituted. With some auxiliary calculation, it may also be possible to make RESRAD more useful for application to off-site scenarios.

We want to suggest that everyone concerned with this assessment pay less attention to soil action levels and instead concentrate on the relationship between particular measured or hypothetical sets of radionuclide concentrations in soil and the predicted maximum annual dose to each scenario subject. When uncertainties in environmental parameters are introduced, soil action levels will become more cumbersome to deal with and will offer little, if any, advantage.

We have some recommendations for DOE and the developers of RESRAD. We are aware that the evolving Windows graphic user interface (GUI) is intended to make the program more accessible to a variety of users, but this greater utility comes at a cost to some potential users. It often is desirable to link programs together, with outputs from one becoming inputs to another. The procedure is usually implemented by writing scripts, which are control programs for the process (Unix operating systems are particularly hospitable to this approach). But a GUI defeats script-driven executions. We are not suggesting that the GUI be eliminated, because it is probably the preferred access for the majority of users, but we

do urge DOE and the RESRAD developers to facilitate a way of bypassing the GUI and launching RESRAD from the command line.

The pieces for this mode of interaction are already in place. The GUI is currently implemented as a separate program, which interacts with the user and the database files and ultimately writes input files for a separate program, RESMAIN3, which the GUI executes through the operating system. RESMAIN3 is the computational engine for RESRAD and is executable from the command line. It reads two auxiliary files, which provide information needed for dynamic allocation of storage arrays, and it reads a data input file specified from the command line (the GUI writes this file, and Version 5.82 gives it the filename extension RAD). RESMAIN3 writes the results of the calculation to a set of files with the extension REP ("REPort"). The data input file is formatted in conformity with the FORTRAN NAMELIST input protocol, in which variables to be initialized in the program are listed by name in the input file and equated to the desired values. By preparing this file with the necessary names and values (a somewhat tedious undertaking) and adjusting the auxiliary file DIMENSION.DAT appropriately, a user can execute RESMAIN3 without invoking the GUI program.

Our recommendation is (1) that this launching mechanism be preserved in future versions of RESRAD, and that its relative independence of the GUI be maintained, so that the program can be launched directly from the command line or from a scripting program, without invoking the GUI front-end, and (2) that the procedure be documented so that users desiring to prepare the NAMELIST-formatted input file, make the modifications in DIMENSION.DAT, and run RESRAD from a script or wishing to run some preprocessing program on the input can do so. Primarily, the documentation should explain how each dimension value in the file DIMENSION.DAT is derived. It should explain the details of the auxiliary files KIFLG.DAT and KIFLG30.DAT (which are related to the decay chains). And it should define every variable in the NAMELIST-formatted input file, with units, and indicating conditions under which the variable is or is not used by RESRAD. There may also be other information that would be useful. This documentation could be printed in an appendix of the user's guide or it could be made available on the RESRAD web site.

We also recommend that DOE consider releasing the source code for RESRAD, making it available for downloading from a web site. We believe this change of policy would have three advantages: (1) Analysts using Unix workstations could recompile the code to function on their platforms, at least with command-line launching as we described in the previous paragraphs (having not seen the source code for the GUI, we do not know how difficult the conversion would be for that module). (2) Analysts with a good knowledge of programming can often resolve puzzling and subtle questions about what is being computed by referring to the source code. (This point is not intended to suggest that the developers do not support RESRAD and try to answer users' questions; as far as we know, the program is well supported.) (3) Experience seems to indicate that many useful suggestions for improving the program and the models it implements would come from programmers and analysts whose participation is currently precluded. In cases where there is particular concern about the authenticity of numbers imputed to RESRAD, it seems that some protocol could be developed that would require "final" or "official" results to be produced with a DOE-provided executable.

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## **RFCA Stakeholder Focus Group Attachment**

**Title:** Answers to the following questions:  
Activity 1: Regulatory Analysis: What questions will we ask the peer reviewers?  
Activity 2: Computer Model Evaluation: What topics do you want discussed at the first workshop?  
Activity 2: What date / time would you like to hold the first workshop?

**Date:**

**Author:** Christine Bennett  
AlphaTRAC, Inc.

**Phone Number:** (303) 428-5670

**Email Address:** [cbennett@alphatrac.com](mailto:cbennett@alphatrac.com)

## **Appendix A**

**Joe Goldfield  
RFSALOP**

## Activity 1: Regulatory Analysis:

Evaluate the criteria used for setting limits on the effects of radionuclides on exposed citizens; should the dose be 15 mRem, 25 mRem, or whatever?

What is the validity of the risk factors developed for the various health doses measured in mRem?

## **RFCA Stakeholder Focus Group Attachment F**

**Title:** Answers to the following question:  
Activity 1: Regulatory Analysis: What questions  
will we ask the peer reviewers?

**Date:** January 3, 2001

**Author:** Joe Goldfield  
RFSALOP

**Phone Number:** 303 321-7276

**Email Address:** joeg1918@aol.com

ADMIN RECORD



## Activity 1: Regulatory Analysis:

Evaluate the criteria used for setting limits on the effects of radionuclides on exposed citizens; should the dose be 15 mRem, 25 mRem, or whatever?

What is the validity of the risk factors developed for the various health doses measured in mRem?

January 9, 2001

Dear Stakeholder:

The Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group will meet at the **Arvada City Hall, 8101 Ralston Road, Anne Campbell Room**, on January 17, 2001 from 3:30 to 6:30 p.m.

The agenda for the January 17, 2001 meeting is enclosed (Attachment A). We will discuss the following topics:

- Progress Report on Agency Use of Focus Group Input
- New Science Outline and Wind Tunnel Detail Presentation/ Discussion
- RSAL Workshop Topics and Formats
- RESRAD Model Workshop – Objectives and Topics
- Land Use Scenarios Presentation and Frame Discussion

The meeting minutes for the January 3, 2001 meeting are enclosed as Attachment B.

At the January 3, 2001 meeting, the Stakeholders requested a list of the issues / questions which are raised in the meetings. The list is Attachment C. Included in this list is a request for the location in the RAC report where RESRAD code differences are addressed. Attachment D is a description of the new air model used at Argonne National Laboratory entitled, "Evaluation of the Area Factor Used in the RESRAD Code for the Estimation of Airborne Contaminant Concentrations of Finite Area Sources." Attachment E is Section 4.2 of the Task 2 RAC report, describing the change in the air model between the 5.61 and 5.82.

Please think about what areas interest you for the upcoming RSAL workshops; i.e., technical, regulatory, policy, model parameters, dose conversion factors, risk slope factors, ALARA, etc. and bring your ideas to the next meeting.

Also enclosed is Attachment F, another submittal for the questions to the Peer Reviewers.

If you need additional information to prepare you for the Focus Group discussion on January 17, 2001, please contact Christine Bennett of AlphaTRAC, Inc. at 303 428-5670 (cbennett@alphatrac.com). Christine will help to find the appropriate resource for you.

You may call either Christine or me if you have any questions, comments, or suggestions concerning the RFCA Stakeholder Focus Group or the upcoming meeting.

Sincerely,

ADMIN RECORD



RFCA Stakeholder  
December 6, 2000  
Page 2 of 2

C. Reed Hodgkin, CCM  
Facilitator / Process Manager

# Meeting Planner

<b>Date Scheduled:</b> January 18, 2001				
<b>Meeting Title:</b> RSAL Working Group				
<b>Purpose:</b> Discussion				
<b>Desired Result:</b> expectations for presentation; new decisions; finalize scenarios				
<b>Locations:</b> CDPHE in the Cleere Room, Building A, 1 <sup>st</sup> Floor				
<b>Meeting Method:</b>			<b>Meeting Type:</b>	
<b>Facilitator:</b>			<b>Recorder:</b>	
<b>Group Leader:</b>			<b>Time Keeper:</b>	
<b>Schedule Time</b>			<b>Actual Time</b>	
<b>Start:</b>	<b>Stop:</b>	<b>Total:</b>	<b>Start:</b>	<b>Stop:</b>
8:30	11:30	3 hrs.		
			<b>Mtg. Cost</b>	
			<b>\$</b>	
<b>Group Members to Attend</b>			<b>Group Members to Attend</b>	
Mark Aguilar – EPA			John Corsi – K-H	
John Marler – RFCLOG			Richard Graham – EPA	
Victor Holm – RFCAB			Jim Benetti – EPA Las Vegas	
Russell McCallister – DOE/RFFO			Susan Griffin – EPA	
Karen Reed – EPA			Sandy McCloud – DOE	
Bob Nininger – K-H				
Rick Roberts – RMRS				
Carl Spreng – CDPHE				
Diane Niedzwiecki – CDPHE				
Tom Pentecost – CDPHE				
<b>Items to be Discussed</b>				<b>Lead</b>
1.	RECAP of last couple of weeks		30 min.	Mark A.
2.	Finalize Scenario OVERVIEWS		30 min. – 5 min ea.	Leads
3.	Decision for Final Report		60 min	Rick R.
4.	Strawman Bare Ground		10 min.	Carl S.
5.	Steve's Expectations – Slides, overheads, ????		10 min.	Mark A.
6.	Expouse Unit Question		10 min.	Carl S.
7.	Decisions & Actions		15 min	Sandy M.
8.	Agenda for 1/25/01		15 min	Mark A.

